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RADIATION DOSE AND RADIATION RISK TO FOETUSES AND NEWBORNS DURING X-RAY EXAMINATIONS

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Abstract

The purpose of this study is to determine the way in which the demands set by degree 423/2000 by the Ministry of Social Affairs and Health are fulfilled with respect to the most radiosensitive groups, the foetus and the child, by estimating the radiation dose and radiation risk to the foetus from x-ray examinations of an expectant mother's pelvic region, finding out the practice involved in preventing doses to embryos and foetuses and assessing dose practices in cases where an embryo or foetus is or shall be exposed, and by estimating radiation dose and risk due to the radiation received by a newborn being treated in a paediatric intensive care unit.

No statistics are available in Finland to indicate how many x-ray examinations of the pelvic region and lower abdomen are made to pregnant patients or to show the dose and risk to the foetus due these examinations. In order to find out the practices in radiological departments concerning the pelvic x-ray examination of fertile woman and the number of foetuses exposed, a questionnaire was sent to all radiation safety officers responsible for the safe use of radiation (n = 290). A total of 173 questionnaires were returned.

This study recorded the technique and Dose-Area Product of 118 chest examinations of newborns in paediatric intensive care units. Entrance surface doses and effective doses were calculated separately to each newborn. Based on the patient records, the number of all x-ray examinations during the study was calculated and the effective doses were estimated retrospectively to each child. The radiation risk was estimated both for the foetuses and for the newborns.

According to this study, it is rare in Finland to expose a pregnant woman to radiation. On the other hand, with the exception of pelvimetry examinations, there are no compiled statistics concerning the number of pelvic x-ray examinations of a pregnant woman. There was no common practice on how to exclude the possibility of pregnancy. The dose to a foetus was not calculated either before or after the pelvic x-ray examination of an expectant mother. The responsibility for counselling an expectant mother about the risk of a radiation

dose to the foetus was not determined. In conventional pelvic x-ray examinations, the dose to the foetus varied from 1 to 2 mSv/exposure. A proposal for a guide to good practices in the pelvic x-ray examination of women of reproductive age is given.

The effective doses of 118 chest x-ray examinations to 43 newborns (gestational age from 26 to 42 weeks) were estimated. The effective dose from one chest radiograph varied from 7.5 μSv to 54 μSv. Retrospectively, the total number of radiation examinations to these newborns totalled 399 during the study; the mean was 9.3 (range 1–40). 98% of the examinations were produced during the first treatment period after birth. The total effective dose per child varied from 0.31 mSv to 3.7 mSv. The radiation risk of fatal childhood cancer due to the mean dose of 0.37 mSv is $3.7 \cdot 10^{-5}$.

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Avainsanat säteilyannos, säteilyriski, sikiö, raskaus, vastasyntynyt, efektiivinen annos

Tiivistelmä

Tämän tutkimuksen tarkoituksena on selvittää STM:n asetuksen 423/2000 vaatimusten täyttymistä säteilyherkimpien ryhmien, sikiön ja lasten osalta, arvioimalla sikiölle odottavan äidin lantion alueen röntgentutkimuksista aiheutuva säteilyannos ja -riski, kartoittamalla käytäntö fertiilissä iässä olevien naisten lantionalueen röntgentutkimusten suorittamisesta sekä arvioimalla teho-osastolla hoidossa olevan vastasyntyneen säteilyannos ja -riski.

Suomessa ei ole tilastoa raskaana oleville naisille tehdyistä lantion ja ala-vatsan alueen röntgentutkimuksista eikä sikiölle näistä tutkimuksista aiheutuneesta säteilyannoksesta tai -riskistä. Fertiilissä iässä olevan, ala-vatsan ja lantion alueen röntgentutkimukseen tulevan naisen raskauden mahdollisuuden poissulkemiskäytännön ja säteilylle altistuneiden sikiöiden määrän selvittämiseksi lähetettiin kyselylomake kaikille säteilyn käytöstä vastaaville johtajille (n=290). Kyselylomakkeita palautettiin 173.

Tässä tutkimuksessa selvitettiin tutkimustekniikka ja annoksen ja pinta-alan tulo 118 lasten teho-osastoilla tehdyssä keuhkojen röntgen-tutkimuksessa. Pinta-annos ja efektiivinen annos laskettiin erikseen jokaiselle lapselle. Potilasasiakirjojen perusteella selvitettiin lapselle tehtyjen röntgentutkimusten lukumäärä tutkimusjakson aikana. Efektiivinen annos arvioitiin retrospektiivisesti jokaiselle lapselle. Säteilyriski arvioitiin sekä sikiöille että vastasyntyneille.

Tämän tutkimuksen mukaan raskaana olevien naisten röntgen-tutkimukset Suomessa ovat harvinaisia. Toisaalta, pelvimetriatutkimuksia lukuun ottamatta, ei ole olemassa tilastoa raskaana olevien naisten lantion alueen röntgentutkimusten lukumäärästä. Yhtenäistä käytäntöä raskauden mahdollisuuden pois sulkemisesta ei ollut. Äidin lantion alueen röntgen-tutkimuksesta sikiölle aiheutunutta säteilyannosta ei arvioitu ennen röntgentutkimusta, eikä myöskään jälkikäteen. Kenellekään ei ollut määritelty vastuuta informoida odottavaa äitiä sikiölle aiheutuvasta säteily-

riskistä. Tavanomaisessa lantion röntgentutkimuksessa sikiön annos vaihteli välillä 1–2 mSv/tutkimus. Tässä tutkimuksessa annetaan ehdotus ohjeeksi hyvästä käytännöstä fertiili-ikäisten naisten lantion alueen röntgentutkimuksissa.

Efektiiviset annokset arvioitiin 118 keuhkotutkimuksesta, jotka oli tehty 43 vastasyntyneelle (lapsi syntynyt 26–42 raskausviikolla). Efektiivinen annos yhdestä keuhkotutkimuksesta vaihteli välillä 7,5 µSv–54 µSv. Näille vastasyntyneille tehtiin tutkimusjakson aikana yhteensä 399 röntgentutkimusta, keskiarvo oli 9,3 tutkimusta lasta kohden (vaihteluväli 1–40). Tutkimuksista 98 % tehtiin ensimmäisen hoitojakson aikana syntymän jälkeen. Efektiivinen kokonaisannos lasta kohden vaihteli välillä 0,31 mSv–3,7 mSv. Keskimääräisestä efektiivisestä annoksesta (0,37 mSv) aiheutuva lapsuuden aikainen syöpäriski on $3{,}7 \cdot 10^{-5}$.

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Abbreviations

AEC	Automatic Exposure Control
ALARA	As Low As Reasonably Achievable
AP	Anterior–posterior
BEIR	Committee on the Biological Effects of ionising Radiation Board on Radiation Effects Research Commission on Life Sciences National Research Council
CEC	Commission of the European Communities
CNS	Central Nervous System
CT	Computed Tomography
DAP	Dose Area Product
ESD	Entrance Surface Dose
FMRI	Foetal magnetic resonance imaging
HUCH	Helsinki University Central Hospital
ICRP	International Commission on Radiological Protection
IQ	Intelligence Quotient
LET	Linear Energy Transfer
MED	Council Directive 97/43/Euratom of 30 June 1997 on health protection of individuals against the dangers of Ionising radiation in relation to medical exposure
OR	Odds Ratio
PCXMC	PC program for x-ray Monte Carlo
PICU	Paediatric Intensive Care Unit
RDS	Respiratory Distress Syndrome
RIS	Radiological Information System
RR	Relative Risk
SIR	Standardised Incidence Ratio
STM	Sosiaali– ja terveysministeriö, Ministry of Social Affairs and Health
STUK	Säteilyturvakeskus, Radiation and Nuclear Safety Authority of Finland
UNSCEAR	The United Nations Scientific Committee on the Effects of Atomic Radiation

“Life is a risky process – so risky that none of us will escape it alive” (Hendee 1991).

1 Introduction

The balance between beneficial effects and unwanted damage is often hard to find when ionising radiation is used purposely or when radiation protection measures are going to be taken. Decisions about how to regulate radiation exposure have to take into account the physical, medical, political, economic and ethical aspects of radiation exposure as well as take into consideration both the individual and collective dose of the population. (International Commission on Radiological Protection 1991, Christensen 2000).

According to the Council of the European Commission (1997), the Council Directive 97/43/Euratom on the health protection of individuals against the dangers of ionising radiation in relation to medical exposure has to be implemented in Member States of European Union. In Finland it was implemented by decree 423/2000 of Finnish Ministry of Social Affairs and Health concerning patients and by law 1142/1998 concerning radiological personnel. According to the decree, “special protection requirements are needed in childhood and during pregnancy”. These demand appropriate radiological equipment, practical techniques and ancillary equipment for the medical exposure of children. The quality assurance programmes, including quality control measures and patient dose, need special attention (Council of the European Commission 1997). In 2000, there were 4.1 million x-ray examinations (0.79 examinations per inhabitant) in Finland, including 4114 pelvimetry x-ray examinations (Hakanen 2002) and 348 400 x-ray examinations of children under 16 years of age in 1995 (Heikkilä et al. 1998). According to Rytömaa (2003), about 1000 new cancer cases/year appear in Finland due to ionising radiation and 120 of them are due to medical exposure (Servomaa & Komppa 1998).

It is considered that patient protection can be improved by continuously comparing local practice with the dose reference levels of doses to patients (International Commission on Radiological Protection 73, 1996). Leitz (2003) believes in a five percent dose reduction, which means 800 manSv/year in Scandinavia. All measured doses should be saved together with the individual exposure data (kV, mAs, grid use, image receptor system and the generator) (Schneider 1998). This is important because the dose received by a patient should be estimated afterwards (Sosiaali- ja terveysministeriö 2000) and according to many studies, the effective dose varies widely – even in the same examination and with similar imaging receptors (Kettunen 1996, European Commission 1996, Rannikko et al. 1997a, Hieta & Rautio 2000, Kettunen &

Servomaa 2003). A study of children undergoing chest radiography showed that some children received 40 (Schneider et al. 1993), even 71-fold doses, the lowest dose measured (Doll & Wakeford 1997). Chest (63.7%) and abdomen (11.2%) x-ray examinations are the most common for children up to 1 year of age (Jones et al. 2001, Siironen 2003). In a CT examination, it is possible to reduce the dose to infants (children less than 1 year of age) between 35 to 70% by optimising the scanning parameters suitable for infants (Chan et al. 1999, Huda et al. 2001, International Atomic Energy Agency 2001). The weight of a newborn (a child less than four weeks of age) may range from 0.360 kg to 6 kg or more and exposure parameters should vary similarly (Chapple et al. 1992, Lindskoug 1992, Martin et al. 1994, Wraith et al. 1995, McDonald et al. 1996, Ruiz et al. 1996).

The United Nations Scientific Committee on the effects of Atomic Radiation (UNSCEAR 1993) has emphasised that due to the highly mitotic state of a child's cells, radiation risk is strongly dependent on the child's age at the time of exposure. Radiation exposure in the first ten years of life is estimated to produce a risk of the total aggregated and the radiation dose to the foetus increases the risk of cancer by about 6% Sv^{-1} (International Commission on Radiological Protection 84 2000, Paile 2002a). In addition to age, individual differences between human beings are also important (Dowsett et al. 1998, Cook et al. 2001, Mustonen et al. 2002). Individuals with certain diseases (ataxia, teleangiectasia) have increased risk of carcinogenesis from ionising radiation (Land 1995) but these deviant groups are small and are not significant in general (Auvinen 2002). Newborns that are premature or ill from birth may require a number of x-ray examinations during their early weeks and this may bring about a marked radiation dose. The number of premature infants increased in 1987–2000 from 4.9% to 5.6% of newborns (Marttila 2003).

From stochastic point of view, there is no evidence at present of a threshold to the radiation dose below which there is no risk. This means that any radiation dose, no matter how small, can have a potential harmful effect. The probability – but not the severity – of stochastic harm increases along with increased exposure. (Committee on the Biological Effects of Ionizing Radiation 1990, International Commission on Radiological Protection 60, 1991). The detriment must include not only the estimates of fatal cancer but also other deleterious effects of radiation. The International Commission on Radiological Protection 60 (1991) considers the components of the detriment due to the radiation exposure of the whole body to be at low doses. These include the risk of fatal cancer in all relevant organs and a specific allowance for differences in latencies, which results in different values of expected life lost to fatal cancer in different organs. They also include an allowance for morbidity resulting from induced nonfatal cancers and for the risk of serious hereditary disease in all future generations from irradiated individual. Detriment can best be thought of as the probability of causing a level of total harm judged to be equivalent to one death caused by a loss of about 15 years lifetime. (Committee on the Biological Effects of Ionizing Radiation 1990, International Commission on Radiological Protection 60, 1991, Marshall et al. 1994, International Commission on Radiological Protection 73 1996, International Commission on Radiological Protection 84, 2000). The natural spontaneous risks to an embryo or foetus during pregnancy of bearing a handicapped child is about 3% (Brent 1980) and in the United Kingdom, the natural incidence of severe mental retardation in adolescence is about 4–5 per 1000 (Mole 1979). The natural cumulative risk of fatal childhood cancers at the age of 15 years is about $7.7 \cdot 10^{-4}$ (National Radiological Protection Board 1993a).

All individual medical exposure should be justified in advance by taking into account the specific objectives of the exposure and the characteristics of the individual involved. The referring physician and the practitioner should seek, where practicable, to obtain previous diagnostic information or medical records relevant to the planned exposure and consider this data in order to avoid unnecessary exposure. All doses due to medical exposure for radiological purposes should be kept as low as reasonably achievable and consistent with obtaining the required diagnostic information whilst taking into account economic and social factors (ALARA). (International Commission on Radiological Protection 60, 1991, Gron et al. 2000, Niittylä 2000, Niittylä & Kahlos 2000). The clinical responsibility regarding individual medical exposure attributed to a practitioner involves justification and optimisation. These include clinical evaluation of the outcome, co-operation with other specialists and staff, obtaining information, if appropriate, concerning previous examinations, providing existing radiological information and/or records to other practitioners and/or prescribers as required and giving information as appropriate on the risk of ionising radiation to patients and other individuals involved (Council of the European Commission 1997, Sosiaali- ja terveysministeriö 2000). Before a diagnostic procedure is performed it should be determined whether a patient is, or may be, pregnant and whether the foetus is in the primary radiation beam. In Finland, there are about 400 000 pelvic and lower abdomen plain x-ray examinations, 36 000 barium enema and urinal x-ray examinations and about 40 000 pelvic and lower abdomen CT examinations per year (Hakanen 2002). In every case of known or possible foetal exposure to ionising radiation, a foetal dose estimate has to be produced and the results of this estimate have to be conveyed to the woman's physician. The pregnant patient has the right to know the magnitude and type of expected radiation risks to her baby as a result of foetus exposure. (Laki potilaan asemasta ja oikeuksista 1992, Pettersson et al. 2003). A methodology for performing dose calculations, a standard letter and information package to present to physicians must be developed. It is recommended that the current set of references, upon which both estimates and reports could be based, be put into use in radiological departments. (Council of the European Commission 1997, European Commission 1998, Karam 2000).

The purpose of this study is to determine the way in which the demands set by degree 423/2000 by the Ministry of Social Affairs and Health to protect the most radiosensitive individuals are fulfilled by estimating the radiation dose and radiation risk to the foetus from x-ray examinations of an expectant mother, to find out the practices involved in preventing does to embryos and foetuses and dose estimation practices in the cases when the embryo or foetus are exposed and to estimate radiation dose and risk due to the radiation exposure of one special group: newborns treated in a paediatric intensive care unit. A further aim of this study is to develop a proposal that will act as a guide for good practices during the pelvic or lower abdomen x-ray examination of a woman of reproductive age.

2 Review of the Literature

The review of the literature consists of the concepts radiation risk and detriment, radiation doses to the foetus and newborns and the factors affecting these doses. The keywords used in searching for articles from the databases were radiation dose, radiation dose and pregnancy, radiation dose and foetus, radiation dose and child, radiation risk, radiation dose and newborn, radiation dose and infant, effects of ionising radiation. The databases used were Medline and Medline Public, Cinahl and Journals Ovid Full Text and Inis (the database of the International Atomic Energy Agency, IAEA).

2.1 Radiation Risk and Detriment

The question of the genetic and somatic risks of ionising radiation was known at the beginning of 20th century (Auvinen 2002). It came widely to the forefront of attention in the aftermath of World War II when nuclear weapons were developed and employed over Hiroshima and Nagasaki. Since then, the field of radiation genetic risk estimation and risk estimates themselves have evolved and several important advances have been made. Up to about the mid-1980s, this evolution was driven primarily by progress in mammalian radiation mutagenesis studies, especially mouse studies, with much less impact from that in human genetics. The situation began to change in the early 1990s with the incorporation of emerging human genetics (human molecular genetics) into the conceptual framework of risk estimation. (Sankaranarayanan 2000, Auvinen 2002).

The effect of exposure is measured as a radiation risk, which expresses the probability of an event, e.g. of dying from cancer. Risk can be expressed as *relative risk* (RR), which is the probability of the disease due to radiation exposure compared to the reference population without exposure (Auvinen 2002). For instance, if in ten years' follow-up, the incidence of thyroid cancer is 10 per 100 000 person years in the group of exposed persons and 5.8 per 100 000 in the unexposed comparison group, the relative risk of thyroid cancer among the exposed is 10/5.8 = 1.7 (a 70% higher risk among exposed). Another possibility is to use *absolute risk*, which is the occurrence of the disease expressed as a probability (Auvinen 2002). In this example, the absolute risk of thyroid cancer among exposed persons is $1\cdot10^{-5}$ per year. Applied to the previous example, this gives an absolute excess risk of (10–5.8) 10^{-5}/Sv = $4.2\cdot10^{-5}$/Sv (Committee on the Biological Effects of Ionizing Radiation 1990, International Commission on Radiological Protection 60, 1991, Dowsett et al. 1998, Auvinen 2000, International Commission on Radiological Protection 64 2001). Chapple et al. (1994) found in their study that the maximum risk was between $8.4\cdot10^{-6}$/Sv and $3.9\cdot10^{-5}$/ Sv. They point out that lifetime risks may be by a factor of up to 2–4 times greater than this. Ringertz and Bremmer (2001) have given an example of the relations: if age at exposure is less than 10 years, the relative lifetime risk of detrimental effects is 1 and if the age is from 30 to 40 (over 50) years, the risk is between 0.25–0.35 (0.15–0.20).

The protection of the foetus and children needs particular consideration because they are highly radiosensitive during the entire period of prenatal development (International Commission on Radiological Protection 90, 2003). The risk to the newborns or to the foetus may be 2–3, or even 4 times, as high as that in the population of 30–40 years of age and 5–7 times greater than after the age of 50 years. (International Commission on Radiological Protection 60, 1991, Brent 1992, Chapple et al. 1992, National Radiological Protection Board 1993a, International Commission on Radiological Protection 73, 1996, Cook et al. 1998, Dowsett et al. 1998, Auvinen 2000, Karam 2000, International Commission on Radiological Protection 84, 2000, Cook et al. 2001, Paile 2002a).

2.2 The Effects of Ionising Radiation on the Embryo, Foetus, and Newborns

2.2.1 Biological Effects

The biological effects of radiation are caused by a damage in DNA which cannot be repaired by the cell itself (Nias 1998a, Paile 2002b). The effects can be grouped into deterministic and stochastic. Deterministic effects are clinically observable only if the radiation dose is above a certain threshold. The severity of the effect (massive cell killing) increases with the dose. (International Commission on Radiological Protection 60, 1991, Le Heron 1992, Nias 1998b, International Commission on Radiological Protection 84, 2000, International Commission on Radiological Protection 2001, Mettler 2001). The cells in children and foetuses undergo rapid division during the growth of the different organs and they become specialised into function in the role that they eventually get in the mature organism. Both cell division and differentiation into mature functional cells are connected with radiation sensitivity. (Prasad 1995, Christensen 2000, Paile 2002b).

Stochastic effects from radiation can result from mutational changes in cells that retain their ability to divide (unprepared or misrepaired DNA damage). These modified cells may sometimes initiate a malignant transformation of a cell, leading to the development of a malignant clone and eventually to a cancer. The period between the initiation and the manifestation of the disease may extend from a few years (leukaemia, thyroid cancer) to several decades (colon and liver cancer). In addition, genetic effects may be initiated due to the irradiation of germ cells (hereditary effects). For stochastic effects, no threshold dose is assumed and the probability of their occurrence is believed to be proportional to the dose. Therefore, keeping the dose as low as possible should reduce the probability of their induction. (International Commission on Radiological Protection 60, 1991, National Radiological Protection Board 1993a, European Commission 1998, International Commission on Radiological Protection 84, 2000, International Commission on Radiological Protection 2001). The recent results indicate that low doses may be more harmful than believed earlier (Hall 2002, Paile 2002b, Hall et al. 2004). Exposure to the pelvic region (pelvis and abdomen) of a pregnant woman may cause the death of the foetus, malformation, growth retardation, mental retardation and heritable effects. These deterministic effects have a quite high threshold (generally above 1 Gy). The problem in radiation protection is the possibility of stochastic effects; even only one hit can induce mutation, a DNA strand(s) break and years later a cancer – if the cell cannot repair the damage. (Travis 1997, International Commission on Radiological Protection 89, 2002, International Commission on Radiological Protection 90, 2003).

The classic triad of radiological embryological syndromes is lethal effects, congenital malformations and growth disturbance (Travis 1997). The function of many organs and tissues is not affected by small reductions in the number of available healthy cells (International Commission on Radiological Protection 60, 1991, UNSCEAR 1993, Sharp et al. 1998, Nakashima et al. 2002). This is why it has been presumed that none of these potential hazards presents a significant problem at the low exposures (0.01–0.1 Gy) used in conventional diagnostic procedures (Sharp et al. 1998).

The effects of radiation exposure on an embryo depend on the time exposure occurs in relation to conception. The development of the unborn child can be divided approximately onto three major phases: the pre-implantation (from conception to implantation; 1–9 days after fertilisation), major organogenesis (4–9 weeks of pregnancy) and the foetal development or foetal stage (from the 9th week of pregnancy until birth). (Travis 1997, Timins 2001, Jacquet 2002, International Commission on Radiological Protection 90, 2003).

2.2.2 Lethal Effects on the Embryo

The most radiosensitive period (for the criterion of lethality) is the first three weeks after conception (Prasad 1995). The most likely result of excessive radiation during this pre-implantation stage is spontaneous abortion (miscarriage), which may go unnoticed because of the high background rate (up to 35%) (International Commission on Radiological Protection 60, 1991, Ornoy et al. 1996, Dowsett et al. 1998, European Commission 1998, Sharp et al. 1998, Karam 2000, Paile 2002a). This is the reason why radiation exposure of the embryo in the first 3 weeks following the conception is not likely to result in any detriment to a live-born child (International Commission on Radiological Protection 60, 1991, International Commission on Radiological Protection 73, 1996). The death of an embryo is usually caused by cytogenic damage during the implantation period. Post-implantation death reaches its maximum 16 days after conception. (International Commission on Radiological Protection 90, 2003).

2.2.3 Malformation of the Foetus

The major formation of the central nervous system takes place during the 8th to 15th weeks of pregnancy, when it is most radiosensitive; from weeks 16 to 25 it has lesser sensitivity (International Commission on Radiological Protection 60, 1991, International Commission on Radiological Protection 2001, Timins 2001, International Commission on Radiological Protection 90, 2003) and after week 25, the foetal central nervous system is relatively radio resistant (Schull & Otake 1999). During the period of main organogenesis, there may be some malformations in the organs under development at the time of exposure. (International Commission on Radiological Protection 84, 2000, Timins 2001, Paile 2002a). Studies have shown that it is possible to produce some malformation mutation during the first days of pregnancy (International Commission on Radiological Protection 90, 2003), but it is rare.

Lower than expected intelligence quotient (IQ) values have been reported in some children exposed in uterus in Hiroshima and Nagasaki; about 30 IQ points per Sievert relate to the dose to the unborn child from the 8th to 15th weeks (International Commission on Radiological Protection 73, 1996, Otake et al. 1996, Otake & Schull 1998). There was also a dose-related increase in the frequency of children classified as "severely retarded". Severe mental retardation was observed following exposure in the 8th to 15th week after conception (dose over 0.5 Gy) but the possibility it may be caused by significantly lower doses could not be excluded (Servomaa & Paile 1999). Paile

(2002a) gives her opinion that the “finger tips” of radiation-produced mentally handicap are microcephaly and mental retardation. There is no complete understanding of the mechanism by which prenatal irradiation interferes with the complex and precisely programmed development of the mammalian brain and nervous system. (Committee on the Biological Effects of Ionizing Radiation 1990, UNSCEAR 1993, International Commission on Radiological Protection 73, 1996). According to Ornoy et al. (1996), there were no differences in the results of medical and neurological examination or in the motor or cognitive areas between embryonic or foetal children irradiated by low doses (under 5 rad = 50 mGy). According to Damilakis and Tzedakis (2002) and Damilakis et al. (2003a), a conceptus dose investigation is necessary if there is the possibility of a foetal dose higher than 10 mGy.

There is evidence of the effect of a radiation dose on the reduction in the height of atomic bomb survivors (Willman et al. 1994, Nakashima et al. 2002) and among long-term survivors of childhood cancer patients (Sklar et al. 1993, Cicognani et al. 1994, Otake et al. 1994).

The latest study by Hall et al. (2004) indicates that a radiation dose to the brain may produce disturbance in intellectual development at radiation doses equivalent to those of computed tomography. The effective radiation dose in a head CT to infant is 7.6 +/- 3.1 mSv (Huda et al. 2001). Leitz and Jönsson (2001) have reported an average dose of 68 mGy to the brain of adults in Sweden and the dose to infants is assumed to be about 30% higher. According to Brenner et al. (2001), estimated doses to an infant in a head CT are about 100 mGy.

2.2.4 Carcinogenic Effects on the Foetus and Newborn

2.2.4.1 Early Findings in Radiation Detriments

Stewart et al. (1956, 1958) initially reported evidence that diagnostic radiography might be carcinogenic for the foetus. They suggested that radiographic examination during pregnancy had approximately doubled the risk of a child developing cancer. MacMahon (1962) reported very similar findings in the northeastern United States based on contemporary hospital records of exposure. The prevalence rate of abdominal x-ray examinations during pregnancy recorded by Stewart et al. (1956, 1958) was very similar to that recorded in corresponding periods during national surveys in 1957, 1958 and 1970.

The Oxford Survey of Childhood Cancers (OSCC) covers all children in Great Britain less than 16 years of age dying from malignant disease

(5276 case-control pairs in 1981). Nearly three-quarters of the information concerning pregnant women exposed during pregnancy, worldwide, has been obtained by the OSCC. Bithell and Stewart (1975) and Wakeford and Little (2003) analysed the OSCC data and they expressed their uncertainty about the effects of radiation. In these studies, the relative risk is about 1.4 (Bithell 1989, Bithell 1993). The OSCC data showed that the relative risk was highest for cancer deaths occurring between the ages of 4 and 7 years (Knox et al. 1987).

Harvey et al. (1985) conducted a case-control study in Connecticut on over 32 000 twins. Their conclusion was that low-dose prenatal irradiation might increase the risk of childhood cancer. Sorahan et al. (1995) reported an 80% increased risk of cancer in children who received prenatal x-ray exposure. MacMahon (1985) supposed, "It seems likely that the question of the association between foetal irradiation and childhood cancer will fade into medical history unresolved and remain the source of more confusion than enlightenment". According to Wakeford and Little (2003), the OSCC data and the Japanese (atomic bomb) cohort irradiated in-utero support the causal explanation found in case-control studies and implies that doses to foetus in-utero of 10 mSv increase the risk of childhood cancer.

Shea et al. (1997) found that there might be association between preconception paternal x-ray exposure and a baby's birth weight and Meinert et al. (1999) suppose that there may be some connection between paternal preconception exposure and leukaemia, but the result is very uncertain.

In reported studies (Table I), the risk in an exposed group varies but most of them have shown a slightly increased risk of leukaemia following x-ray exposure in-utero. According to Auvinen (2000), the mechanism for greater susceptibility among children remains unclear. In addition, there has been divergence in the radiation protection community regarding the magnitude and generality of the effect of prenatal radiation on the risk of childhood cancer (International Commission on Radiological Protection 90, 2003).

Table I. Prenatal exposure to diagnostic x-rays and risk of childhood cancer.

Reference	Type of Study	Primary site	Number of Subjects Case/control	Risk in exposed group
Bithell and Stewart (1975)	Case-control	All cancers	8.513+8.513	Leukaemia: OR=1.5 Solid tumour: OR =1.5
Kaplan (1958)	Case-control	Leukaemia	150+150	OR=1.4
Ford et al. (1959)	Case-control	All cancers	244+306	Leukaemia: OR=1.6 Other ca: OR=1.8
Polhemus and Koch (1959)	Case-control	Leukaemia	317+317	OR=1.3
Murray et al. (1959)	Case-control	Leukaemia	65+65	OR=0.9
Court Brown et al. (1959)	Cohort	Leukaemia	40,000	SIR=0.9
Gibson et al. (1960)	Case-control	Leukaemia	319+884	OR=1.6
MacMahon(1962)	Case-control	All Cancers	556+7.242	All cancers: OR=1.4 Leukaemia: OR=1.3
Guntz and Atkinson (1964)	Case-control	Leukaemia	102+102	OR=1.1
Ager (1966)	Case-control	Leukaemia	129+217	OR=1.1
Graham et al. (1966)	Case-control	Leukaemia	319+884	OR=1.5
Diamond et al. (1973)	Cohort	Leukaemia	20,000 +35,000	RR=1.6
Monson and MacMahon (1984)	Case-control	All cancers	1.342+14.294	Leukaemia OR=1.4 (age 0–19) OR=1.52 (age 0–9)
Harvey et al. (1985)	Case-control within cohort	All cancers	32+128	Leukaemia: OR=1.6 All cancers: OR=2.4
Rodvall et al. (1990)	Case-control within cohort	All Cancers	95+190	Leukaemia: OR=1.7 CNS: OR=1.5
Stjernfeldt et al. (1992)	Case-control	Leukaemia	216+301	Leukaemia: OR=1.8 Solid tumour:OR=0.9
Naumburg et al. (2001)	Case-control	Leukaemia	624+624	OR=1.14
Shu et al. (2002)	Case-control	Leukaemia	1.842+1.842	OR=1.2[*)] OR=1.0[**)] OR=2.4[***)]

(According to Auvinen 2000, ICRP 90 2003)
[*)] all in-utero exposed
[**)] leukaemia diagnosed < 6 years
[***)] leukaemia diagnosed at 11–14 years of age

2.2.4.2 Latest Conclusions

The latest conclusions attempt to emphasise the practical consequences and potential implications of the updated but still limited knowledge on genetic susceptibility to radiation-induced cancer (Piechowski 2000, Salomaa 2002, International Commission on radiological Protection 90, 2003) and effects in the early stages of gestation (Hall 2002, Jacquet 2002, International Commission on radiological Protection 90, 2003, Hall et al. 2004). A developing embryo and foetus is radiosensitive throughout the prenatal period in-utero. Low radiation doses (less than 0.1 Gy) can cause pre-implantation death caused mainly by cryogenic damage (International Commission on Radiological Protection 90, 2003).

The most vulnerable period for radiation-induced cancer appears to be the first years of life (Naumburg et al. 2001). The age dependence of a radiation-induced risk is observed for the cancers most readily induced by radiation: leukaemia, thyroid cancer and breast cancer (Auvinen 2000). The spontaneous risk of childhood leukaemia and cancer is $(2–3)\cdot10^{-3}$ per Gy and a prenatal radiation exposure of 10 mGy has been reported to increase the risk by 0.06% to 40% (International Commission on Radiological Protection 84, 2000, Timins 2001, Pettersson et al. 2003, Wakeford & Little 2003). For thyroid cancer, a very high susceptibility has been observed up to the age of 4 years. For breast cancer, susceptibility decreases in almost linear fashion until approximately 50 years of age. (Committee on the Biological Effects of Ionizing Radiation 1990, UNSCEAR 1993, Auvinen 2000).

Doll and Wakeford (1997) highlight that the carcinogenic affects of the irradiation of a foetus and child should not be expected to be same. The cells that give rise to most of the typical childhood cancers (other than leukaemia) persist and are capable of dividing for only a short time, if at all, after birth. Bithell and Stiller (1988) modelled the risks by trimester, taking into account the number of x-ray films. The excess relative risk/mGy in the first trimester was 0.28 and in the third trimester, it was 0.03. There is evidence that the low dose irradiation of a foetus in uterus (particularly in the last trimester) causes an increased risk of childhood cancer (Brent 1992, Dowsett et al. 1998, Karam 2000, Timins 2001) and the evidence does not suggest that the risk is not zero at doses of the order of 10 mSv (Wakeford & Little 2002). The increased risk is produced by doses in the order of 10 mGy; in these circumstances, the excess risk is approximately 6% per Gy (1:1700). Without irradiation, one child of five hundred children will get childhood cancer. If the foetus's dose is 10 mGy, it means a 30% higher risk of childhood cancer. A radiation dose of 35 mGy during pregnancy gives a double risk of childhood cancer (Servomaa & Paile 1999); according to Sharp et al. (1998), the risk is double by dose of 25 mGy to the age of 15 years. For United Kingdom national rates, the baseline risk of cancer in the first 15 years of life is 1 in 650 and about half of these cancers are fatal (the excess lifetime fatal cancer risk is 0.5%) (Sharp et al. 1998). Because of the cancer risk, x-ray examinations with high doses of the pelvis (CT, fluoroscopic imaging dose with several tens of mGy) should especially be avoided during (presumed) pregnancy (International Commission on Radiological Protection 84, 2000, Damilakis et al. 2001, Timins 2001, Kusama & Ota 2002). Cardiac catheter ablations (Damilakis et al. 2001) or surgical treatment of hip fractures can be performed, if necessary, during all trimesters (Damilakis et al. 2003b) because in typical procedure, the dose to a foetus is less than 1 mSv. Table II summarizes the effects of the irradiation of a human embryo during different periods in the development of the foetus.

Radiation doses for paediatric x-ray examinations should be kept to a minimum because of the higher risks of radiation exposure to children (Al-Balool & Newman 1998). From the radiation protection point of view, the most important organs are specified by the International Commission on Radiological Protection 60 (1991). In addition, the latest studies have indicated that there may also be some effects on the lower levels (Paile 2002c, Wikman 2002, International Commission on Radiological Protection 90, 2003, Pettersson et al. 2003) and consequently the optimisation of an individual dose is important. Wakeford and Little (2002) point out that the evidence suggests the risk is not zero at doses in the order of 10 mSv. The dose for the foetus is higher in the second and third trimester (Damilakis et al. 2003a) and smaller during the first trimester, with empty bladder (due to the depth of the uterus) (Perisinakis et al. 1999, Damilakis et al. 2001).

Table II. Effects of irradiation on the human embryo.

Days after fertilisation	Period of development	Effects
1 to 9 (1–21)	pre-implantation	Most probable effects: death with little chance of malformation
10 to 12	implantation	Reduced lethal effects; malformation unlikely; intra-uterine growth retardation predominant effect
13 to 50 (22–64)	organo-genesis	Production of congenital malformation; retarded growth
51 to 280 (65–280)	foetal	Effects of CNS; growth retardation at high doses
All	foetal/neonate	Increased incidence of cancer and leukaemia (4^{th} week -)
(Adapted from the International Commission on Radiological Protection 60, 1991, Dowsett et al. 1998, International Commission on Radiological Protection 90, 2003)		

In addition, the latest studies have indicated that there may also be some effects on the lower levels (Paile 2002c, Wikman 2002, International Commission on Radiological Protection 90 2003, Pettersson et al. 2003) and consequently the optimisation of an individual dose is important. Wakeford and Little (2002) point out that the evidence suggests the risk is not zero at doses in the order of 10 mSv. The dose for the foetus is higher in the second and third trimester (Damilakis et al. 2003a) and smaller during the first trimester, with empty bladder (due to the depth of the uterus) (Perisinakis et al. 1999, Damilakis et al. 2001).

2.3 Radiation Doses to the Embryo and Foetus Due to a Mother's X-ray Examinations

Exposure of the pelvis and abdomen should be avoided during pregnancy whenever possible. The examination of pelvic region of a pregnant woman is justified under exceptional circumstances whenever the benefit from the clinical data generated is likely to outweigh the potential risk to the expectant mother or foetus. The management of radiation risk during pregnancy needs good communication and lateral thinking by experienced practitioners. (Council of the European Commission 1997, Parry et al. 1999, International Commission on Radiological Protection 84, 2000). The major practical problem is the detection of early, unsuspected pregnancy prior to radiation exposure (Malone 1997, Sharp et al. 1998, Chahed et al. 2000) or accidental injuries when the expectant mother may be e.g. unconscious. The patient may not be aware of her pregnancy or medical personnel fails to obtain this information (Pettersson et al. 2003). Afterwards, this may cause great anxiety to the pregnant woman (Meller 2003) and legal responsibility to staff. Osei and Faulkner (1999a) reported the results of 50 pregnant women undergoing radiological examination of the lower abdomen or pelvis, when the embryo/foetus was near or included in the x-ray beam. Most of these women were unaware of their pregnancy at the time of their radiological examination. When they afterwards discovered that they were pregnant, they sought advice from their physicians on the foetal dose and risk. The Radiation Protection Advisor estimated the foetal dose based on their knowledge of the technique factors and examination details using normalised uterine doses published by the National Radiological Protection Board. The gestational ages ranged from 2–24 weeks. The data indicated that there was no risk of serious radiation-induced somatic (e.g. cancer induction) or deterministic effects. There opinion is that the in-utero exposure to diagnostic x-rays present a very low total risk to a developing embryo or foetus when compared with the other effects (approximately 30–50% of human embryos abort spontaneously in pregnancies) (Brent 1980, Jones & Russel 1987).

Chahed et al. (2000) analysed 17 cases of pregnant women who were not aware of the pregnancy. The gonad doses were up to 52 mGy. There were four minor abnormalities, but they could not be attributed to the effects of irradiation because of the low dose. However, they suggest that the termination of pregnancy should be justified if the dose to the embryo is over 50 mGy. Generally it is concluded that only very rarely, if at all, will the level of foetal irradiation in diagnostic radiography justify the termination of a pregnancy (Chahed et al. 2000, Fenig et al. 2001). Only in women who have undergone several x-ray examinations in which the foetus is in the primary x-ray beam or when both radiographic and fluoroscopic examinations have been performed, it is necessary to calculate or measure the level of radiation. Abortion should be considered when the dose level is above 50–100 mGy (Ornoy et al. 1996, Fenig et al. 2001). Berlin (1996) reported two cases. The first was 28-year-old woman who underwent a series of lower gastrointestinal and chest radiographs. The dose was 10 mGy (the foetus was 4 weeks in gestational age). The other case was a 30-year-old woman who was given 25.75 MBq of iodine-131, a dose 3.4 mGy (the foetus was 5 weeks in gestational age). The 30-year-old patient went into a labour prematurely and she gave birth to an infant with multiple congenital anomalies (the foetus died two months later). The 28-year-old-woman had a full-term pregnancy; this child had several birth defects, including microcephaly and congenital heart disease (cf. Paile 2002a).

Damilakis et al. (2000) reported the foetal dose during a CT examination of the abdomen varied from 33 to 46 mGy in the second trimester and 28 to 42 mGy in the third semester. In Iran, there were over 1340 Iranian pregnant patients exposed to diagnostic x-rays from 1984–1994. The age of the pregnant patients varied from 15 to 51 years. The average foetal dose was 6.8 $\pm$3.81 mGy with over 10 to 90 mGy (more than 37%) (Ardabi 2001). In Sweden, Pettersson et al. (2003) conducted a 12-month survey in three hospitals where they examined 28 000 woman aged 15–50 years and 21 cases of exposure to pregnant patients were reported. In the second phase, the RIS (radiological information system) data and national population records of woman aged 15–50 years were connected. They found 299 cases of foetal exposure out of 19 000 x-ray examinations carried out in three hospitals, which indicates that 1.5% of the female patients were pregnant during the x-ray examination. The reported foetal doses are summarised in Table III.

Table IIIa. Approximate Foetal Doses from Diagnostic Procedures.

Examination	Sharp [1)] et al. (1998) mean (max)	Parry et al. (1999)	Osei & Faulkner (1999, 2000) mean (range)	Toppenberg et al. (1999)	Wagner et al. (1997) mean (reported range)	Metzger & Van Riper (1999)	Fenig et al. (2001)	Internet [****)] (2003)
	mGy	mGy	mGy	mGy	mGy	mGy	mGy	mGy
Conventional X-ray exams								
Abdomen (ap)	1.4 (4.2)	2.5	2.6 (0.26–15)	2.45	2.5 (0.25–19)		2.2	2.2
Abdomen (pa)			1.3 (0.64–3.0					
Chest	<0.01		>0.01	0.0001	(0.002–0.43)		<0.05	0.005
iv. urogram	1.7 (10)	2.5	4.8 (2.9–6.8)		6 (2.7–41)			5.9
Lumbar spine ap	1.7 (10)	4	4.2 (0.09–10)	3.9	4 (0.27–40)	7.2		
Lumbar spine lat			0.91 (0.09–3.5)					
Lumbosacral spine			1.1 (0.10–2)		4 (0.30–23)		7.2	
Pelvis	1.1 (4)	2	3.4 (1.4–15)	0.4	2 (0.55–22)		2.1	2.1
Hips and femur		3	0.9 (0.11–2.1)	2.13	3 (0.73–14)		1.2	1.2
Femur (distal)					(0.01–0.50)		0.01	0.001
Skull	<0.01		<0.01	0.04	<0.005–0.003		<0.005	<0.005
Thoracic spine	<0.01		<0.01	0.09	(0.10–0.55)		0.11	0.11
Dental				0.001	(0.0003–0.001)		0.0006	0.0006
Shoulder					(0.005–0.003)			0.005
Extremities				0.01	(0.005–0.18)		<0.005	<0.005
Pelvimetry							12.7	12.7
Mammography				0.2	(< 0.1)		<0.1	<0.01
Cervical spine				0.02			<0.005	0.005

(continued)

Table IIIa. (continued)

Fluoroscopic exams								
Upper GI. barium meal	1.1 (8.1)	1	1.5 (0.1–2.3)	0.56	1 (0.05–12)		1.7	1.7
Barium enema	6.8 (24)	10	6.1 (0.3–10.4)	39.86	10 (0.28–130)		9	9
Hysterosalpingography					10 (2.7–92)			
ERCP							3.29	
Urinary bladder			3.9 (0.56–11)				15	
Pyelography		6		13.98			5.9	
Urethrocystography					(2.7–41)			15
Computed tomography								
Abdomen	8.0 (49)	30		26*)				20
Chest	0.06 (0.96)	0.16	1.2 (1.0–1.4)	1*)				0.2
Hand	<0.005							
Lumbar spine	2.4 (8.6)			35**)				
Pelvis	25 (79)		89 (65–114)					
Skull (head)	<0.005			<0.5*)				
Pelvimetry	0.2 (0.4)			2.5***)				
Liver			3.6 (2.0–4.4)					

1) ICRP adopted these values
*) 10 slices
**) 5 slices
***) scout film
****) Internet www.motherrisk.org/cancer/pregnancy.php3

Table IIIb. Approximate Foetal Doses from Diagnostic Procedures.

Examination	Tapiovaara et al. (1997)	Helmrot et al. (2003)	Ferguson (1996)	Mann et al. (2000)	Health Canada (2003)	Chahed et al. (2000)	Tung & Tsai (1999)	Reiman (2003)	Pataramontree et al. (2001)
	mGy	**mGy**		**mGy**	**mGy**	**mGy**	**mGy/ film**	**mGy**	**mGy**
Conventional X-ray exams									
Abdomen	1.55	0.44–0.63		2 /exp	1.4		0.082		
Chest	0.0002	0.001			>0.01	0.1	0.00156	<0.001	
iv. urogram		2.8						7.3	2.63
Lumbar spine		1.28–1.75			1.7			3.4	0.35
Lumbosacral spine							0.070		
Pelvis		0.66–0.72			1.1		0.334	1.7	0.29
Hips and femur		0.12						1.3	
Femur (distal)									
Skull									
Thoracic spine								<0.001	
Cervical spine								<0.001	
Dental					<0.01			<0.001	
Shoulder									
Pelvimetry			2.2/exp						
Ribs								<0.001	
Mammography					<0.05	0.16			

(continued)

Table IIIb. (continued)

Fluoroscopic exams									
Upper GI					1.1			39	1.47
Barium enema		7.8			6.8				33.5
Hysterosalpingography						12			
Pyelography									3.68
Pelvic angiography			10 mGy/ min						
Cardiac catheterization							13		
Computed tomography									
Abdomen		13.8–15.6		5 /slice				20	48.4 + / - 16.4
Chest		0.21			0.06			<0.01	0.09 + / - 0.04
Hand									
Lumbar spine					2.4–8				
Pelvis					25			10	
Skull (head)					<0.005			<0.01	
Trauma		15.8							

2.3.1 Preventing a Radiation Dose to an Embryo and Foetus

Women of reproductive age presenting for an examination in which the primary beam irradiates directly, or by scatter, the pelvic region (essentially any ionising irradiation between the diaphragm and the knees) or for a procedure involving radioactive isotopes should be asked whether they are or may be pregnant. The prescriber and the practitioner should ask whether she is pregnant. If pregnancy cannot be excluded, special attention should be given to the justification, particularly the urgency, and to the optimisation of the medical exposure, taking into account the exposure both of the expectant mother and the unborn child. This is especially important if abdominal and pelvic regions are going to be exposed (International Commission on Radiological Protection 60, 1991, Council of the European Commission 1997, Dowsett et al. 1998, Schneider 1998, Sharp et al. 1998, International Commission on Radiological Protection 84, 2000, Sosiaali- ja terveysministeriö 2000, International Commission on Radiological Protection 2001, Faulkner 2002). If the patient cannot exclude the possibility of pregnancy, she should be asked if her period is overdue. The problem is that understanding the practice of and the radiation protection guidelines for females is inconsistent and there is significant unfamiliarity with the protection rules internationally and nationally, even within a hospital (Abd El-Bagi et al. 2001, Faulkner 2002) because of the lack of an international consensus.

If there is no possibility of pregnancy, the examination can proceed. If the patient is definitely, or probably, pregnant (i.e. menstrual period overdue) the justification for the proposed examination should be reviewed by the radiologist and the referring physician. They have to make a decision on whether to defer the investigation until after delivery or until the next menstrual period has occurred. However, a procedure of clinical benefit to the mother may also be of indirect benefit to her unborn child and a delay in an essential procedure until later in pregnancy may increase the risk to the foetus as well as to the mother. If pregnancy cannot be excluded, but the menstrual period is NOT overdue and the procedure gives a relatively low dose to the uterus, the examination may proceed. If the examination gives relatively high doses (e.g. abdominal and pelvic CT, IVUs or fluoroscopy), there should be discussion taking into consideration locally agreed recommendations. In all cases, if the radiologist and the referring physician agree that the irradiation of the pregnant or possibly pregnant uterus is clinically justified, this decision should be recorded. The radiologist must then ensure that the exposure is limited to the minimum required to acquire the necessary information. If it becomes obvious that a foetus has been inadvertently exposed, despite the above measures, the small risk to the foetus due to the exposure is unlikely to justify, even at higher doses, the greater risks of invasive foetal diagnostic procedures (e.g. amniocentesis) or those of a termination of the pregnancy. When such inadvertent exposure has occurred, an individual risk assessment based on the knowledge of the technique factors, simulating the examination using a phantom loaded with dosimeters or reviewing scientific literature, should be made by a radiation physicist and there should be discussion with the patient concerning the results. (European Commission 1998, Sharp et al. 1998 Goldman & Wagner 1999, Timins 2001, Faulkner 2002).

2.3.2 Practice of X-ray Examination if the Patient is Pregnant

The International Commission on Radiological Protection (1977) put forward in publication 26 a proposal for a so-called 10 day rule, which was later reversed in publication 60 (1991) because of new knowledge. Statute 423 (2000) and MED directive (1997) strongly stress the importance of avoiding the unnecessary irradiation of a pregnant woman. Before an x-ray examination, the presence of pregnancy should be evaluated if the woman is of reproductive age. This means that a woman between the ages of 12 and 50 years should be asked explicitly orally or in writing whether she might be pregnant or may have missed a period (International Commission on Radiological Protection 84, 2000, International Commission on Radiological Protection 89, 2002). The outcome of such questioning should be recorded (Timins 2001). Menstrual history may or may not be reliable in determining pregnancy. For example, a young girl who comes to hospital with her parents may deny a pregnancy that she suspects (International Commission on Radiological Protection 84, 2000). The use of contraceptives such as the contraceptive pill or coil does not necessarily guarantee non-pregnancy. (Council of the European Commission 1997, European Commission 1998). Surveys of attitudes in individual centres indicate wide variations in practices e.g. in Europe. Some centres use the 10-day rule (x-ray examinations of the pelvic region should be performed during the 10-days following the onset of a period). In other centres, the 28 days rule is used (if the patient is not sure if she is or is not pregnant, the date of the last period is checked and if it started more than 28 days previously, consideration would be given to postponing the examination) (Hart 1994, Malone 1997, Sharp et al. 1998, Faulkner et al. 2001). Some would regard pregnancy as unlikely unless the patient reported a missed menstrual period. Others routinely undertake pregnancy tests, despite the questionable reliability of such tests in very early gestation. It would appear that considerable misunderstanding exists even among radiation specialists. Bury et al. (1995) put forward a proposal to revive "the 10 days rule" if the dose to the uterus is high (>10 mSv). Malone (1997) and the National Radiation Protection Board (1993a) propose the use of "ten-day rule" in situations where the foetal dose will contribute up to "several tens of mGy". In such cases the examination should be done with 10 days of the start of a period (Bury et al. 1995). In low dose examinations, the examination can be performed if the uterus is out of the beam or if the patient is not pregnant (Council of the European Commission 1997). The referring physician when writing the referral has to find out whether the embryo or foetus will be in the direct beam and whether the procedure is a relatively high-dose examination (International Commission on Radiological Protection 84, 2000). The professional who performs the examination has final responsibility for the irradiation of the foetus. According to the law on patients' rights (Laki potilaan oikeuksista 1992), a patient has right to decide herself whether the examination is to be performed, after she has received information about the risk to the foetus, the advantages of the x-ray examination and the possibilities of other modalities.

The exclusion of pregnancy would be less critical for a patient undergoing diagnostic radiography of the wrist or head than for the patient having a CT of the abdomen (Meller 2003); an examinations between knees and diaphragm needs attention (Bury 1995). The European Commission (1998) issued a schematic overview that gives a guide on how to check whether a patient is pregnant (Appendix A).

2.3.3 Guidelines for Preventing a Dose to an Embryo or Foetus Due to X-ray Examinations

In order to minimise the frequency of unintentional radiation exposure to an embryo and foetus, there should be an informative poster in hospital waiting rooms with the text: "Patients, staff and relatives: Please inform the staff if you think that you might be pregnant" (Appendix B) (European Commission 1998). A picture of a pregnant woman in the poster captures the attention of people who cannot read or are from other countries. ICRP 84 (2000) proposes the same idea:

"IF IT IS POSSIBLE THAT YOU MIGHT BE PREGNANT, NOTIFY THE PHYSICIAN OR RADIOGRAPHER/TECHNICIAN BEFORE YOUR X-RAY EXAMINATION."

These types of advisory notices should be posted at several places in radiological departments to increase the awareness of women of reproductive age coming for an x-ray examination. This information is particularly important in reception area and other areas where diagnostic x-ray equipment is used (Berlin 1996, European Commission 1998, Sharp et al. 1998, International Commission on Radiological Protection 84 2000, Arranz et al. 2001, European Community 2001, Faulkner et al. 2001, Timins 2001).

In some cases, women arrive unconscious and receive a predetermined “trauma series” of x-rays immediately upon arrival. A CT examination may follow these if internal injuries seem likely. In such cases, the patient’s health depends on accurate information about potential injuries and, if the woman’s life were at risk, knowledge of pregnancy would not lessen the need for such procedures. (Goldman & Wagner 1999, Karam 2000). According to Mann et al. (2000), approximately 30% of all trauma victims are female in their childbearing years (10–50 years old). Of these trauma victims, 15% are definitely or possibly pregnant at the time of injury. Especially in those cases but also for protecting the medical staff in the event of a poor outcome of the pregnancy, it is important to record the technique used in the x-ray examination for latter requirements (Goldman & Wagner 1996, Karam 2000, Mann et al. 2000).

According to Finnish laws in force (Council of the European Commission 1997, Sosiaali- ja terveysministeriö 2000), the x-ray technique should be recorded in order to later assess a patient’s dose from an x-ray examination. To estimate the dose, the documentation of technical factors (whether a grid was used, peak voltage, dose rate, fluoroscopy time, films and projections used) is particularly important for a patient of childbearing age (Goldman & Wagner 1999, International Commission on Radiological Protection 84, 2000, Timins 2001, International Commission on Radiological Protection 89, 2002).

2.3.4 Basic Principles When Planning the X-ray Examination of a Pregnant Patient

When pregnancy is confirmed but exposure to ionising radiation is unavoidable, the referring physician and the physician directing the exposure and the patient should discuss three questions. The discussions should cover topics including <u>justification</u> for the procedure and maintaining maternal health, with emphasis on the relevance of maternal wellbeing for the continuation of the pregnancy. Discussions should include consideration of the urgency of the exposure: only procedures deemed critical to maternal health would be acceptable. The risk-benefit considerations for the radiology of a pregnant woman are complicated because the risks to both mother and child must be considered. These should include an assessment of the risk to the mother if the examination is postponed with regard to benefits; the mother receives a direct benefit, whereas the foetus usually benefits indirectly (Osei & Faulkner 1999a, Faulkner et al. 2001).

Optimisation of the exposure to ensure that doses are kept as low as reasonably achievable (ALARA), consistent with obtaining the required diagnostic information (International Commission on Radiological Protection 60, 1991, UNSCEAR 1993, International Commission on Radiological Protection 89, 2002). If the prescriber and the practitioner justify the examination, taking into account pregnancy, it is the ultimate responsibility of the mother to decide if the examination should be performed after being informed of the possible consequences to the unborn child (European Commission 1998, Laki potilaan asemasta ja oikeuksista 1992). The dose to the unborn child should be estimated before the examination is carried out and, if relevant, reassessed afterwards (Council of the European Commission 1997, European Commission 1998). There may be situations when a series of conventional radiographs of the lower abdomen could be precipitated. In these situations, the cumulative dose should be estimated (Faulkner et al. 2001).

As a psychosocial issue, the situation prescribed above is very complicated because the natural instinct of the mother is to avoid a risk of the foetus. In many situations, it appears to be a natural reaction to minimise risks of serious damage. Thus, with elective procedures, many could not accept a low probability risk where the damage may be significant, as they see no need to take the risk. In such circumstances, it is arguably improper for a profession to remove the right of the individual not to take the risk through not providing them with the knowledge that they are exposed to it. This is a matter of great sensitivity; individuals should be entitled to make a fully informed decision about how they will determine their own course of action. This area is very problematic. (International Commission on Radiological Protection 60, 1991, Bury et al. 1995, Malone 1997). With trauma patients, when a mother’s life is in a danger, the possibilities of deleterious radiation effects never outweigh foetal or maternal survival (Goldman & Wagner 1999).

2.3.5 Factors Effecting on the Dose of the Foetus

The actual foetal dose depends on radiographic equipment used, the size of the patient, the location (or position) and the size of the foetus and the methods used to perform the examination and whether the foetus is in the primary x-ray beam (Rannikko et al. 1997b, Mann et al. 2000).

The foetal dose also depends on the depth of the foetus in the maternal body, since tissues lying between the surface of the patient and the pregnant uterus attenuate the x-ray beam entering the body. The position and size of the foetus change during the course of pregnancy. (Osei & Faulkner 1999b, Damilakis et al. 2000) and is significantly related to mother's BMI as seen in Figure 1. During the first trimester, the embryo depth ranges from 4 to 10 cm depending on the individual (Perisinakis et al. 1999). The main reasons are the status of the bladder and the maternal BMI.

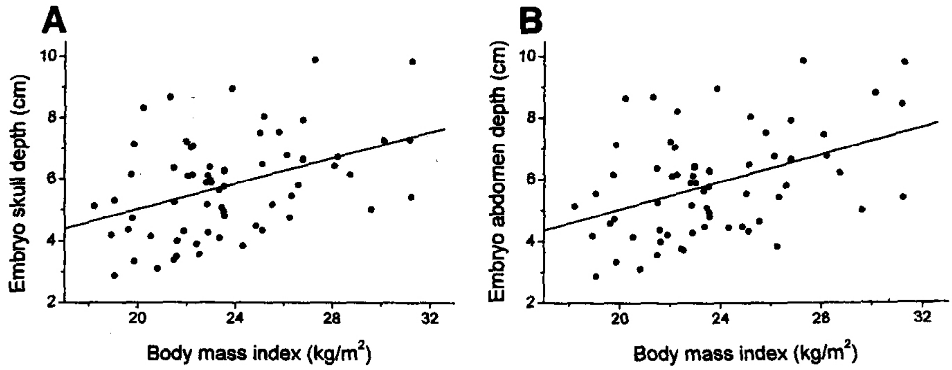

Figure 1. The embryo skull (A) and abdomen depth (B) related to mother's BMI (body mass index (Adopted from Perisinakis et al. 1999).

During the first trimester, the embryo dose is approximately the same as the uterus dose (Osei & Faulkner 1999a) but in the second and third trimester, it is not equal to the uterus dose (Damilakis et al. 2003a). Table IV shows some examples of the radiation doses to the foetus in different trimesters in computed tomography (CT) and in one angiographic procedure.

In Barium Enema radiation, the dose varies from 19 mGy to 81 mGy and it is under 50 mGy if the fluoroscopy time is less than 7 minutes (Damilakis et al. 1996). Appendix E summarises examples of radiation doses to the foetus in a single helical CT and in a multislice (four-slice) CT.

The amount of exposure is an important factor in increasing the radiation dose to the foetus. Table V shows approximate foetal doses per single radiograph in the abdomen or pelvis, with the foetus in the primary field, compared with mother's thickness.

Table IV. Approximate foetal radiation doses from diagnostic procedures at different gestational ages.

Examination	**First trimester** **mGy**	**Second trimester** **mGy**	**Third trimester** **mGy**
Chest Helical CT Winer-Muram et al. (2002)	0.0033–0.0202	0.0079–0.0767	0.0513–0.1308
Abdomen CT*) Damilakis et al. (2000)		30.0–43.6	29.1–42
Cardiac catheter ablation*) Damilakis et al. (2001)	0.1018–0.2043	0.3	0.557
*) Depth of the conceptus 5.5 cm, 8.5 cm and 11.5 cm			

Table V. Estimated foetal dose for a single radiographic view of the abdomen or pelvis with the foetus in the primary field.

Patient thickness cm	**Estimated dose (mGy)**	
	Ap view	**Lateral view**
14–15	1	0.7
16–19	1.5	1
20–23	2.1	1.5
24–26	3.1	2
27–30	4.3	3
31–34	5.6	4
Adopted El-Khoury and Madsen (2003)		

Table VI summaries the main technical factors affecting the radiation dose to a foetus in different modalities using x-rays.

Table VI. Factors affecting foetal radiation dose from radiological procedures.

Exposure mode/factor	Explanation	Comments
	All x-ray modalities	
Beam filtration	Aluminium filtration is used to harden beam by absorption of low-energy photons that will not penetrate tissue to produce image	Increasing filtration will reduce dose
Tube current (mA)	The current generated by the tube during the radiology series	Lower mAs produces lower dose
Tube voltage kV_p	The tube voltage on the electrons that generate the x-ray beam	Increasing kV_p gives more energetic photons and lower dose
	Conventional x-ray	
Number of films and	There may be multiple films of some locations Some of the shots will have marginal impact on radiation dose to conceptus (foetus in direct beam or not)	Fewer films means lower dose Shots of extremities and head produce virtually exposure to the conceptus
	Fluoroscopy	
Fuoroscopy	Most fluoroscopy units will retain the last image hold	Shorter fluoroscopy time results in smaller dose
Distance to patient	The patient-tube distance will vary depending on the size of the patient and the geometry of the setup	Greater distance reduces the dose
	CT	
Slice thickness	The thickness of the slice of tissue imaged during each pass of the CT	Dose is largely independent slice thickness, assuming beam collimation is properly set
Pitch	The distance between adjacent slices, which might not be contiguous	Greater pitch reduces dose Dose increases with narrow slices
Number of slices and location of uterus	The total number of slices Slices exposed the conceptus in the primary field. In addition, there will probably be more slices (and more secondary radiation) either above or below the conceptus in beam area	A lower number of slices results in lower exposure because of reduced dose from scattered radiation)
(In accordance with Karam 2000)		

Foetal size and depth are important when estimating foetal dose during the second and third period of pregnancy (Osei & Faulkner 1999a, Damilakis et al. 2000, Damilakis & Tzedakis 2002) but as seen in Table VII, so are the used tube peak voltage and filtration influence to the foetus dose. It is possible to reduce the dose to the foetus in an x-ray examination of the pelvic region about 70% by optimising the imaging technique, film-focus distance, the peak voltage, cassette's material and film-screen combination (Grondin et al. 2004).

Table VII. Normalized conceptus dose data in mGy/mGy for an AP abdominal examination performed on a pregnant woman during the second and third trimesters (12-pulse generator, FSD 100 cm, field size 34x32 cm, phantom thickness 26.4 cm on second and 29.4 cm o the third semester).

	Total filtration (mmAl)					
kVp	**Trimester**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**
80	Second	0.439	0.455	0.474	0.487	0.504
	Third	0.359	0.372	0.389	0.403	0.413
90	Second	0.490	0.506	0.526	0.543	0.567
	Third	0.402	0.415	0.431	0.445	0.456
100	Second	0.531	0.546	0.565	0.578	0.592
	Third	0.436	0.451	0.465	0.476	0.489
(In accordance with Damilakis et al. 2002).						

The relative dose to the foetus by PCXMC decreases strongly when the foetus is outside the primary beam (Figure 2). When the foetus is more than 10–12 cm from the exposed area, the dose to the foetus is theoretical. (Servomaa & Kettunen 2004).

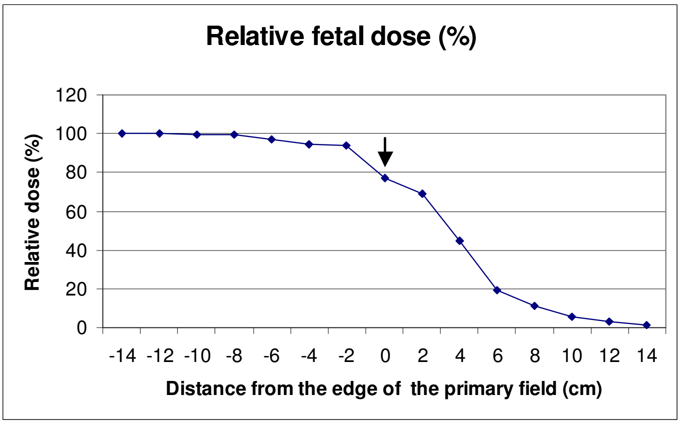

Figure 2. Effect of the foetus distance from the edge of the primary beam to the relative dose of the foetus (FSD 100 cm, 80 kV, 3 mmAl, 20x20 cm^2).

A posterior-anterior projection will give a lower dose to the embryo than anterior-posterior project (Appendix C) (Osei & Faulkner 1999a, Osei & Faulkner 1999b, Damilakis & Tzedakis 2002) because the mother's body absorbs radiation. In computed tomography (Parry et al. 1999), according to Wagner et al. (1997), the dose to the middle of the patient is 70% of the surface dose with a variation $\pm$30%. The inaccuracy depends on beam energy, patient size and scanning volume. If a surface dose of 30 mGy is in the pelvic region, the conceptus dose is between 12 mGy and 30 mGy.

2.3.6 Special Radiological Examinations During Pregnancy

For many years, x-ray pelvimetry was the standard for providing anatomic dimensions and a quantitative assessment of the maternal pelvis; the use of ultrasound examination has significantly reduced the number of x-ray pelvimetries (Claussen et al. 1985, Thomas et al. 1998). In Finland, there were 5,083 pelvimetry x-ray examinations in 1996 (Rannikko et al. 1997a) and 4,121 in 2000 (Hakanen 2002). Usually, an x-ray pelvimetry examination is taken during the 36th to 40th weeks of pregnancy (Standertskjöld-Nordenstam et al. 1988). In conventional x-ray examinations with a grid, this comes to 3 exposures of the patient; two small field area exposures in the anterior position and one large area field in the lateral view (Borell & Fernström 1960, Axelsson & Ohlsen 1979). The dose absorbed by a foetus from conventional pelvimetry has decreased to 0.46–1 mGy (Russell et al. 1980, Ferguson et al. 1996, Lecomber et al. 1998), from 5–20 mGy per film (Auvinen 2000) in the early 1940s, and can vary up to 40-fold (Thomas et al. 1998). The lowest foetal doses are measured for pelvimetry with a radiography air-gap or rare earth screens (0.1 mGy) and digital plates or fluoroscopy and a digital spot image (0.07–0.12 mGy) (Axelsson & Ohlsen 1979, Badr et al. 1997, Holje et al. 1997, Lecomber et al. 1998). In modified digital CT pelvimetry, the doses have been 0.1–0.44 mGy by the low-dose settings specified and with a lateral topogram and an axial CT slice (Pritchard & Hufton 1981, Federle et al. 1982, Suramo et al. 1984, Adam et al. 1985, Claussen et al. 1985, Moore & Shearer 1989, Ferguson et al. 1996, Badr et al. 1997, Lecomber et al. 1998). The World Health Organization (1999) proposed not to carry out pelvimetry on a routine basis and it should be undertaken only on rare occasions but according to Balleyguier et al. (2003), the multidetector CT is replacing conventional CT pelvimetry because of a shorter acquisition time and easily understood final images.

Ultrasonic examinations provide most of the information required by obstetricians and do not utilise ionising radiation (International Commission on Radiological Protection 84, 2000). During last decade, magnetic resonance imaging of the foetus (FMRI; Foetal Magnetic Resonance Imaging) has gained considerable interest. FMRI is a non-invasive modality and provides better soft tissue contrast and the possibility of tissue characterisation both with 0.5 T and with 1.5 T MRI systems. (Hata et al. 1990, Revel et al. 1993, Garel et al. 1998, Michel et al. 2002).

2.4 The X-ray Examinations of Newborns in an Intensive Care Unit

Diagnostic radiology plays an important role in the diagnosis and treatment of newborns (including premature infants born under 37 weeks of gestational age) requiring intensive care. The alveolar epithelial cells secrete surfactant, which decreases the surface tension at the interface between the air and alveolar surface, maintaining patience of the alveoli and preventing collapse of the lung, at 23 to 24 weeks (Godderidge 1995). Radiographs are most commonly taken in the neonatal period to assist in the diagnosis and management of respiratory difficulties. Respiratory distress syndrome (RDS), also called hyaline membrane disease due to the lack of surfactant (Clements & Avery 1998), pneumonia, pneumothorax, collapsed segment of lung, position of the umbilical arterial catheter or an endotracheal tube, are the main indications for taking a chest x-ray (Fletcher et al. 1986, Arroe 1991, Donoghue 2000). Intestinal infections (necrotic enterocolitis) are indications of an abdominal x-ray of a newborn (Swingler et al. 1998, Lowe et al. 1999, Jones et al. 2001). The overall incidence of RDS is approximately 1% of all infants (Zimmerman 1995) and in these cases, characteristic chest x–ray findings show a ground-glass haze in the lung surrounding air-filled bronchi (air bronchogram), characterized by diffuse reticulogranular infiltrates, atelectasis and air bronchograms, often progressing to severe bilateral opacity. (Walther & Taeusch 1992, Marttila 2003). In Finland, the overall incidence of RDS among premature infants with very low birth weight (under 1000 g) and surviving for more than 12 hours was 760 per thousand (Tommiska et al. 2001).

The most premature infants are still at the greatest risk for severe RDS and frequently develop complications (e.g. infection, patent ductus arteriosus and central nervous system haemorrhage) which all contribute to prolonged requirements for oxygen and ventilator support (Marttila 2003). According to Greenough et al. (2000), the majority of very immature infants have an abnormal chest radiograph appearance. However the number of bedside chest radiographic examinations performed each year increases because the intensive care of the premature infants have improved during last decades strongly (Wilson-Costello et al. 1996).

Two projections of chest and abdomen are produced during the prenatal period: either as a single exposure usually taken at the first exposure time (anterior posterior supine chest and abdomen and lateral chest and abdomen) or as two separate exposures from chest and abdomen ap and lateral (Heikkilä et al. 2001, Jones et al. 2001). There is no significant difference in effective doses between these two techniques (Jones et al. 2001) if it is necessary to evaluate both the chest and abdomen region. The criteria for a good image are peak inspiration, no rotation or tilting, the cervical trachea to T12 /L1 must be included and pulmonary vessels and trachea and major bronchi must reproduce. In addition, the diaphragm and costo-phrenic angles must be visually sharp and the paraspinal lines, retrocardiac lung and mediastinum should be clearly reproduced. The recommended technical values for exposure for an 800 g, 29-week-old newborn are 62 kV, 0.8 mAs, 2.5 mmAl and a 400-speed screen-film combination and no grid. The accurate collimation of the x-ray beam (chest; to diaphragm, chest and abdomen; also pelvis), lead rubber shield on the incubator or on the baby immediate proximity to the beam are also required. (Godderidge 1995, European Commission 1996, Cook et al. 1998). Later, only the chest ap is taken as a matter of routine and the chest and abdomen ap or lateral view is taken only when the paediatrician separately asks for the projection. Other examinations are quite rare during the neonatal period (Wilson-Costello et al. 1996, Heikkilä et al. 2001, Siironen 2003).

Although many diagnostic studies in paediatric intensive care units (PICU) are made routinely for the purposes of monitoring and surveillance, the value and incremental gain of repeated chest radiographs are frequently not considered (Pollack et al. 1987). The value of routine chest radiographs in critically ill patients has been evaluated (Hauser et al. 1989, Sivit et al. 1989, Hall et al. 1991, Spitzer et al. 1993, Marik & Janower 1997, Swingler et al. 1998, Greenough et al. 2001) with varying recommendations for the frequency of chest radiographs. Performing routine daily chest radiography is justified by the assumption that a significant percentage of routine chest radiographs shows a clinical pathologic process requiring medical intervention (Greenbaum & Marschall 1982). Others believe the use of routine portable chest radiographs to be unwarranted (Sanada et al. 1991, Brainsky et al. 1997). Some suggest that decreased variability in ordering practice and fewer chest radiographs per patient results cost savings to the patients and payers (Hauser et al. 1989, Price et al. 1999). The value of daily chest radiographs is not supported simply by whether they show new findings but that these findings change treatment (Marik & Janower 1997, Helfaer 1999, Greenough et al. 2000, 2001). Hakulinen (1992) reported on the premature infants at the age of two years and born in the Kuopio area from 1978–1982, 3% had chronic BPD (Broncho-Pulmonal Dysplasy). According to Marttila (2003), the incidence of RDS has changed towards lower gestational age due to the decreased incidence rate among preterm infants born after 30 weeks.

2.4.1 Specific Features of the Premature Infant as a Client in Radiological X-ray Examination

The overall number of births per year in Finland decreased from 60 223 in 1987 to 57 371 in 2000 but the rate of preterm births increased from 5.6% to 6.3% (Marttila 2003) including about 3000 premature infants born in Finland every year. About 300 of them are under 1000 g in weight (extremely low birth weight, ELBW) (Korhonen 1996). The smallest premature infants require the special treatment given in the PICU in university hospitals. The smaller the premature infant is the more exacting care is needed and the more x-ray examinations are taken (in small sampling 10–41, on average 21 times/baby (Korhonen & Perttunen 2002); premature infants weighing less than 750 g on average 31 x-ray examinations/infant (Wilson-Costello et al. 1996). In addition, a small premature infant has no (or very low) resistance to infections and other disturbances. The skin of a premature infant is very thin and there is very little fat under the skin. The head of a premature infant is big, the area of the body in relation to the weight of the body is large and the system is immature. That is why a premature infant needs all its energy to grow and to maintain body temperature. If the cassettes put in an incubator are cold or the doors of the incubator are open for too long, the baby loses temperature. Because the body tries to keep the optimal temperature stable, it uses all possible energy to produce heat and it may be exposed to metabolic disturbances. The need for extra oxygen increases, which is why all energy needed for recovery is spent on heating. (Godderidge 1995, Korhonen 1996). It has been estimated that a 3.5 kg foetus consumes about 53.3 kcal/kg/d to enable a weight gain of 120 g. This estimate is based on an oxygen usage of 5 ml/kg/min. If an oxygen usage of 8 ml/kg/min is assumed, the energy requirement is 74.6 kcal/kg/d; the weight gain requires about 17.5 kcal/kg/d. The daily energy requirement for a foetus is 100–140 kcal/kg/d. (Korhonen 1996).

Depending on her or his age, a premature infant often needs respiratory treatment or support for ventilation to get sufficient oxygen (Greenough et al. 1999). The intubator tube has to remain without moving when the baby is raised to get the image receptor under its back. In addition, other possible wires have to be taken in consideration. (Godderidge 1995). Pain rates the heartbeat and blood pressure and lowers oxygenation. Changes in blood circulation act as an intermediary and may even lead to cerebral haemorrhage. Assessment of the pain felt by premature infant is difficult and needs a lot of experience. Despite this, one of the babies' basic rights is get treatment for her or his pain. The aim of nursing is that the vital functions of the infant remain stable and that the infant has no pain and is protected against infection.

All these facts have to be taken into consideration when giving premature infant an x-ray examination. The radiographer has to plan the x-ray examination carefully in advance and then work very quickly, gently and effectively to disturb the baby as little as possible. (Godderidge 1995, Korhonen 1996) Newborns are non co-operative and the frequency of breathing is fast, causing the possibility for higher retakes. (Wall et al. 1986, Chapple et al. 1992, Wraith et al. 1995). The exposure parameters based on the patient's age are not ideal in all cases, especially with premature infants. According to Lindskoug (1992), in chest examinations, the weight of the patient should frequently determine the exposure parameters. Because of the small size of neonates, a positional shift of just 1–2 cm can bring about a magnitude change in organ doses (Chapple et al. 1994). In chest x-ray examinations, the range of exposure is usually 1–2 (Wall et al. 1986, Almen et al. 1996) but the number of projections and exposures of one patient have not widely been reported (Almen et al. 1996, Wilson-Costello et al. 1996, Mooney & Thomas 1998).

2.4.2 Factors Affecting the Radiation Dose of a Newborn and a Premature Infant

The radiation doses from x-ray examinations carried out in neonatal units must be at a minimum while the quality of the radiographic image is optimised. Wide variations have been found in the techniques, equipment performance and radiation dose in different hospitals both in European and Finnish hospitals (Wraith et al. 1995, Servomaa et al. 2000a). The results indicate that substantial dose reductions could be achieved without loss of image quality both in conventional and digital systems (Schneider et al. 1993, Wraith et al. 1995, Jonsson et al. 1996, Kyriou et al. 1996, McParland et al. 1996, Cook et al. 1998, Bond 1999, Cook et al. 2001). In children's chest examinations, the given EU directives with a sensitivity class of 400–600 seem to be impracticable for the imaging plates (Gindl 2002). Beam energy, filtration and collimation, the use of grid, the anode heel-effect, patient size, the screen-film combination and film processing conditions affect the patient dose in conventional radiography and most of them in computed radiography. In addition, the wide latitude in digital radiography (both imaging plates and large-area detector based on Caesium Iodide/Amorphophous-Silicon or Amorphous Selenium, flat panels) needs attention to avoid the use of excessively high kilovoltages and tube currents in order to reduce possible noise and get better DQE (detective quantum efficiency) and MTF (Modulation Transfer Function). (International Commission on Radiological Protection 34, 1982, Curry et al. 1990, Bushong 1993, Carlton & Adler 1996, Schaefer-Prokop & Prokop 1997, Lowe et al. 1999, Parry et al. 1999) The benefit of digital systems is picture processing, which is very useful with the visibility of pneumothorax and different catheter (Goo et al. 2001).

There are many ways to reduce the dose to children. The selection of high speed screen-film systems (at least speed class 400), which are typical for different examinations and take into consideration the requirement for high resolution, should always be weighted (Almen et al. 1996, European Commission 1996, McParland et al. 1996, Cook et al. 1998, Parry et al. 1999). According to Huda et al. (1996), the computed radiography of the chest requires approximately twice the exposure of a 600-speed screen-film system. In other research, the computed radiography reached by a 25% lower dose with the same image quality as a film-screen system at a speed class 400 (Seifert et al. 1998) and in another with imaging plates necessitates about 75% more exposure (Dobbins et al. 1992, Launders & Cowen 1995). The conclusions have conflicted; the use of digital systems such as imaging plates or flat panels needs more critical evaluation and a new attitude for radiographers and radiologists.

According to Strotzer et al. (2000), because the latitude in digital systems is wide, it is very difficult to overexpose them, which could result in patients being exposed to unnecessarily high doses of radiation. The staff have to know how to choose the optimal dose level to avoid the use of excessively high dose levels "just to make sure" (Jönsson & Leitz 2002). These systems need a lot of attention to get the image quality and dose to the optimal level but the quality of the images must still be good enough (i.e. spatial resolution) for diagnostics (Durand et al. 1995, Maccia et al. 1996, Spahn et al. 2000). According to Samei et al. (2003) and Strotzer et al. (2002), the flat panels give a good resolution and no significant difference in diagnostic quality even with a decreased radiation dose. Völk et al. (2000, 2004), Strotzer et al. (2000) and Hamers et al. (2001) have shown in their studies that it is possible to get a 50% or even 75% decrease in the dose without significant differences in image quality and Ludvig et al. (2002) have shown a 50% decrease in radiation dose compared with the film-screen system speed class 400. A portable flat panel system offers rapid availability in the PICU (e.g. Samei 2003).

The photostimulable phosphors generally have lower x-ray absorption efficiency, which is why they have higher noise levels than screen-film systems for the same radiation exposure. (Huda et al. 1996) Imaging plates and other computed radiography systems (ccd; charge coupled device: flat panel, FPD) are more sensitive to low energy scattered radiation than conventional screen-film combinations because of the lower K-edge absorption energy of imaging plate phosphor (Tucker et al. 1993, Sandborg et al. 1994, Wandtke 1994, Huda et al. 1997, Parry et al. 1999). Seifert (1998) found that added filtration and the use digital radiography could produce dose reduction of 50% in the chest ap radiographs of neonates. Cohen et al. (1989) proved that it is possible to reduce mAs by 25–33% with digital images and still get similar quality images as with the conventional for the same patients. The number of retakes is lower because over or under exposure is rare (Tarver et al. 1990, Lindhardt 1996, Oda et al. 1996, Seibert et al. 1996). Medical imaging management with PACS systems allows better monitoring of radiology practice (UNSCEAR 2000) and makes it possible to have "a second opinion" from a specialised paediatric radiologist via teleradiology systems (Parisi et al. 1998, International Atomic Energy Agency 2001, Pohjonen et al. 2002,).

Image quality is considered to be of primary importance in children's x-ray examinations (Kyriou et al. 1996, Cook et al. 1998). It is strongly advised that the use of an antiscatter grid is unnecessary with infants because infants are small, despite the higher sensitivity to scattered radiation when using imaging plates or flat panels. If there is need for a grid, the same reduction of scattered radiation is achieved with an air-gap (Office for Official Publications of the European Communities 1996, Cook et al. 1998). The patient dose could be reduced substantially by increasing the filtration of an x-ray beam, either with additional filters of aluminium whilst largely maintaining adequate image quality (Wang et al. 1984, Dowsett et al. 1998) or with other materials (Villagran et al. 1978, Chakera et al. 1982, Burgess 1985, Nelson & Jennings 1986, Wesenberg et al. 1987, Massaoumzahed et al. 1998, Doyle & Brennan 1999).

Shrimpton et al. (1988) point out in particular that the small reductions in patient dose from the use of increased beam filtration would be weighted against the cost of such filters, their possible detrimental effect upon image contrast and the concomitant need for additional tube loading. Adequate additional tube filtration of 0.1 mmCu–0.2 mmCu or the equivalent is recommended for equipment having an existing total filtration of about 2.5 mmAl for almost all examination in order to absorb the soft part of the radiation spectrum which unnecessarily contributes to patient dose without significantly affecting image quality (Wraith et al. 1995, European Commission 1996).

With respect to imaging plates, Pärtan (2001) has recommended using rather lower kV than with film-screen combinations because of the decrease of the DQE with over 80 kV (with beam filtration of 2–3 mmAl), although Kump and Shi (1999) found in their experiments that the 117 kV and the large area flat panel (a-Si) had a 2–3 times greater integrated DQE and 2–3 times greater dynamic range compared with a screen-film images. However, high kV techniques, which allow a reduction in mAs and exposure time, produce a significant reduction in dose as well as movement blurring (Chapple et al. 1992, Office for Official Publications of the European Communities 1996, Council of the European Commission 1997, Cook et al. 1998, Rehani 2001, Duggan et al. 2003). That means that the smallest patients need the most powerful machines: 12-pulse or high frequency multi-pulse generators are required because the waveform also affects the dose. For a 10 month old infant, a chest x-ray with identical blackening requires an exposure more than 20-times longer and allows a 2.15 times higher Entrance Surface Dose when a 1-pulse generator is used instead of a converter generator (Office for Official Publications of the European Communities 1996).

Dose saving can also be performed by using low attenuation materials (carbon) in table tops (Sutton & Cranley 1996, Hufton & Russell 1986, Rehani 2001) and cassettes (Hufton & Russell 1986, National Radiological Protection Board 1990, Dance et al. 1997, Brennan & Hourihan 1998). The anode heel effect makes dose reduction possible with a large exposure area and a short film to focus distances because there is less radiation on the anode side and so the right positioning of the output beam reduces dose on the thinner part (Carlton & Adler 1996, Fung & Gilboy 2000).

Lead and rubber shielding of the parts of the body next to the primary beam should always be used in children's x-ray examinations to protect them against primary and scattered radiation. Radiosensitive cell-forming bone marrow is present in most bones at birth. The developing breast, thyroid and gonads are also sensitive to radiation detriment and they must be protected. (Fletcher et al. 1986, Committee on the Biological Effects of Ionizing Radiation 1990, International Commission on Radiological Protection 60, 1991, National Radiological Protection Board 1993b, UNSCEAR 1993, International Commission on Radiological Protection 73, 1996, Office for Official Publications of the European Communities 1996, Cook et al. 1998) In neonatal radiography, a contact vinyl rubber on the infant's body can achieve the best protection. Personal shields should always be used in an incubator because of better hygiene and less loss of the baby's body temperature (Faulkner et al. 1986, Chapple et al. 1994, Wraith et al. 1995, Office for Official Publications of the European Communities 1996, Cook et al. 1998). If that is not possible, a hanging lead can be placed from the collimator to cast a shadow on the primary x-ray beam or a shield lead masking techniques on the top of the incubator lid can be used. (Barcham et al. 1997, Seeram 1997, Statkiewicz-Sherer et al. 1998) The use of a lead shield does not increase the handling time of the baby (Russell & Davies 1986). The radiographer always has to carefully collimate in spite of the use of a lead shield and only the area of interest should be exposed. (National Radiological Protection Board 1990, Radiation and Nuclear Safety Authority 1994, Wilson-Costello et al. 1996, Cook et al. 1998, Palmer et al. 1998, Schneider 1998, Cook et al. 2001, Rehani 2001).

There are many factors to be optimised to obtain an acceptable diagnostic image with the lowest radiation dose (Lindskoug 1992, Bushong 1993, Vano et al. 1995, McParland et al. 1996, Cook et al. 1998) when handling a small newborn with special needs and requirements. A training programme, regular provision of dose information and collaboration between physicist, radiographers and radiologists can significantly reduce the doses received by infants (Martin et al. 1993, Brennan 1995, Almen et al. 1996, Roebuck 1999). Educated and trained staff should take x-ray examinations of children (Schneider et al. 1993, Rannikko et al. 1997a, Schneider 1998, Roebuck 1999, Hogg et al. 1999, Cook et al. 2001). The use of a care sheet for each patient, where the exposure factors for previous examinations are recorded, can assist with the careful choice of exposure factors more individually and even with premature infants (Simpson et al. 1998, European Commission 2000, Duggan et al. 2003)

2.5 Dose Reference Levels in Paediatric X-ray Examinations

Diagnostic dose reference levels are the dose levels given nationally in medical radiological diagnostic practices for typical examinations for groups of standard-sized patients (e.g. for adults 55–85 kg; mean 70 kg) (Havukainen 2001) or standard phantoms for broadly defined types of equipment. The dose reference level corresponds to the 3rd quartile, 75% of individuals receive a dose less than this value, i.e. these levels are expected not to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied (Office for Official Publications of the European Communities 1996, Council of the European Commission 1997). If the doses are too high, in the upper part of dose range, patients may get unnecessarily high doses and if doses are in the lower part, the image quality may be poor (Papadimitriou et al. 2001). It is therefore important to assess image quality in relation to patient dose and be able to get a striking and significant dose reduction. The criteria for good radiographic technique must be also met. (Schneider et al. 1992, 1993.) The European guidelines on the quality criteria for diagnostic radiographic images in paediatrics (European Commission 1996) give an 80 µGy Entrance Surface Dose as the reference level in the chest ap of a newborn. The variation of Entrance Surface Doses in three CEC paediatric trials for a newborn's 1 kg in weight in a chest ap was from 11 µGy to 386 µGy; the mean was 45 µGy. ICRP Committee 3 (2001) has proposed a dose reference levels including the ap chest of newborns (80 µGy) and the NRPB (Hart et al. 2000) has proposed 50 µGy but due to insufficient data, no national dose reference levels have been set in Finland for a child's bedside or a newborn's chest examinations. The knowledge of dose levels in comparison with other centres clearly indicated that there is a plenty of work to do to get a reduction in radiation doses (Warren-Forward et al. 1996).

2.6 Estimation of the Radiation Risk in Childhood Due to Radiation Exposure in the Uterus and After Birth

Risk estimates should be based on the estimated dose and stage of gestation (Osei & Faulkner 2000). Every x-ray examination with the dose of some tens of mGy's to the foetus involves a considerable risk of childhood cancer. The foetal doses should be calculated in every radiological department. On the other hand, Osei and Faulkner (2000) say: “If there are indications for a pregnant woman to undergo a radiological examination, then the radiation risks seem to be small problem compared with the advantages of the examination for the mother or child”. Bithell (1993) has used the Adrian Committee (1958) data with the time-dependent relative risk model to obtain a relative risk coefficient of 0.051 per mGy (95% confidence interval 0.028–0.076). The absolute risk coefficient of 8% per Gy (95% confidence interval 4.4–12.0%) may be derived from the model. (Bithell 1993). Gilman et al. (1988) reached four conclusions based on estimates by the Mantel-Haenszel techniques. Both the timing and dose of a prenatal x-ray examination influence the risk of cancer and the detailed consequences of these factors can be distinguished. They assume that the timing of prenatal exposure is more important than the dose. They also found that the nature of the maternal illness, which occasioned the prenatal x-rays, was not important. They suggest that for first trimester x-rays the cancer risk could be almost three times greater (earlier two times) (Knox et al. 1987) than the risk for other prenatal x-rays and six times as great as the risk for non-x-rayed children (Gilman et al. 1988). Furthermore, Rodvall et al. (1990, 1992) suggested that a developing foetus may be more sensitive to the carcinogenic effects of ionising radiation than children irradiated post-natal.

The National Radiological Protection Board (1993a) has adopted an excess absolute risk coefficient of 6% per Gy for cancer incidence under 15 years of age following low dose irradiation in uterus. Forty percent of the risk was estimated to be due to leukaemia (2.5% per Gy). It is slightly greater than the risk of 1.8% per Gy estimated by the NRBP for a 10 mGy dose received just after birth (Muirhead & Kneale 1989, National Radiological Protection Board 1993b, Osei & Faulkner 2000). The findings in studies by both Bienefeld and McLaughlin (1998) mentioned that the risk of childhood cancer following parental irradiation – preconception or during pregnancy – was equal. Although a number of studies of children exposed to ionising radiation in-utero have found evidence of increased cancer incidence (Knox et al. 1987, Gilman et al. 1988, Rodvall et al. 1990, Rodvall et al. 1992, Bithell 1993, Osei & Faulkner 2000), there are several others where these effects were not observed (Bienefeld & McLaughlin 1998, Osei & Faulkner 2000). The single biggest obstacle to studying this outcome is its rarity: most studies do not have the power to address this question (Bienefeld & McLaughlin 1998, Rytömaa 2003). The association between parental pre-conceptual exposure to radiation and childhood leukaemia is unlikely (Tutty & Brennan 1999). Table VIII shows the hereditary disease and cancer risk in some x-ray examinations (foetus in the primary x-ray beam).

Table VIII. Risk of hereditary disease and cancer following typical foetal diagnostic medical exposure to ionising radiation.

	Probability of disease per mean exposure		
Examination/procedure	**Mean foetal dose (mGy)**	**Hereditary disease**	**Fatal cancer to age 15 years**
Conventional x-ray			
Abdomen	1.4	1 in 30,000	1 in 24,000
Barium enema	6.8	1 in 6,000	1 in 5,000
Barium meal	1.1	1 in 38,000	1 in 30,000
Iv-urography	1.7	1 in 24,000	1 in 20,000
Lumbar spine	1.7	1 in 24,000	1 in 20,000
Pelvis	1.1	1 in 38,000	1 in 30,000
Computed tomography			
Abdomen	8.0	1 in 5,000	1 in 4,000
Lumbar spine	2.4	1 in 24,000	1 in 14,000
Pelvis	25	1 in 1 700	1 in 1 300
(Sharp et al. 1998)			

The uterine dose provides an approximation of the mean dose to the foetus in the first two months of gestation. In later stages of pregnancy, foetal size and depth become more crucial in estimating foetal dose (Damilakis et al. 2000). In literature, some simple rules are shown for the crude first approximation of absorbed dose to the conceptus in three broad categories: low (<10 mGy), intermediate (10–250 mGy) and high (>250 mGy). The doses are estimated at 2, 5 and 10 mGy respectively: 2 mGy per exposure (radiographs), 5 mGy per slice (computed tomography) and 10 mGy per minute of fluoroscopy, when the conceptus is within the x-ray field. (Mann et al. 2000.)

2.7 Methods of Estimating Radiation Doses Due To X-ray Examinations to a Patient

Patient doses in diagnostic radiology can be measured in different ways. The Dose-Area Product (DAP) is the absorbed dose in the air averaged over the area of the radiation beam multiplied by the area of the beam in the plane where dose is measured. It is normally given in $Gycm^2$ or $mGycm^2$. The dose-area is the same wherever in the beam it is measured as long as the chamber receives no scatter from the patient. Before use, the DAP meter must be calibrated. (Le Heron 1992, Toivonen et al. 2001).

The Entrance Surface Dose (ESD) can be defined as the absorbed dose to air at the point where the x-ray beam enters the surface of the patient stressed by the backscatter factor (1.29 to 1.46). The backscatter factor depends on the quality of the radiation beam (energy filtration of the x-ray beam and field size) (Harrison 1983, Tapiovaara 1985, Grosswendt 1990, Cranley et al. 1991, European Commission 1996, Harju et al. 2003). The unit for Entrance Surface Dose is mGy. The entrance Surface Dose can be computed by the formula

$$ESD = BSF \cdot (h_c/h_p)^2 \cdot Q \cdot Y \qquad (2.7\text{-}1)$$

where Q is the output of x-ray beam/mAs at distance h_c, BSF is backscatter factor, h_p is the distance from the focus to patient skin and the Y is the mAs used in examination (Parry et al. 1999, Toivonen et al. 2001). The formula gives a reliable result if data collection is made carefully (Toivonen et al. 2001, Kepler et al. 2003). It is possible to calculate the Entrance Surface Dose from the Dose-Area Product by dividing the Dose-Area Product by the exposed area on the skin of patient and multiplying it with the backscatter factor (BSF) (Chu et al. 1998, Kepler et al. 2003).

$$ESD_{DAP} = DAP_{read} \cdot h_{c*} BSF / A \cdot h_p \qquad (2.7\text{-}2)$$

In formula A, the field size is measured on the film front from the patient examination. DAP_{read} is corrected by the calibration coefficient, which depends on the tube potential. The ESD dose can also be measured directly with a thermoluminescent dosimeter (TLD) (Servomaa et al. 2000a, Vartiainen 2000, Toivonen et al. 2001).

The Entrance Surface Dose (ESD) or Dose-Area Product is suitable and comparable for quickly assessing the practice in different x-ray departments between different x-ray examinations or techniques but they are not very satisfactory as total risk indicators. They are less useful when comparisons of potential radiation detriment are required between different x-ray examinations or techniques. (Le Heron 1992) Energy imparted to patients may be used to study the relationship between the image quality and patient dose (Almen & Nilsson 1996, Gkanatsios & Huda, 1997, Huda & Gkanatsios 1997) but it is complicated to use in every day routine. The effective dose describes the risk or harm caused by radiation to an individual (Council of the European Commission 1997). It is not practical in a routine radiological procedure (Lampinen 2000) but it is useful when making a comparison between different techniques or modalities or assessing the risk of ionising radiation to an individual (Servomaa 2000).

The effective dose was developed by ICRP to reflect the fact that some organs are more sensitive than other organs. They have a higher risk of producing a cancer or another deleterious effect. The effective dose also helps in evaluating the biological effects of radiation (Committee on the Biological Effects of Ionizing Radiation 1990, UNSCEAR 1993, Nias 1998b, UNSCEAR 2000, International Commission on Radiological Protection 89 2002). The effective dose is the sum of the effective doses for exposed organs. The calculation of these doses requires knowledge of the size and configuration of the individual, the geometrical projection of the beam, size and location of the primary and scatter beams, Entrance Surface Dose and x-ray beam energy spectrum. The radiation quality factor is needed because of the different biological effects when interacting with tissue. For x-rays, the quality factor is unity (Lampinen 2000), which according to International Commission on Radiological Protection 74 (1996) and Marttila (2002) means that the effective dose can be defined for x-rays as the sum of the weighted average absorbed doses in all the tissues and organs of the body. The unit is Sv (Sievert). International Commission on Radiological Protection 60 (1991) has produced a list of tissue weighting factors for a number of organs and tissues and they are mean values for the whole population. The calculation of effective dose is based on the Monte Carlo technique described in NRPB-R186 (Jones & Wall 1985) or direct organ dose measurements by TLD (McCollough & Schueler 2000).

Nowadays there are several computer-based programs for calculating the effective dose, e.g. PCXMC and ODS-60 (Tapiovaara et al. 1997), and estimating the dose and risk to the exposed foetus (Rannikko et al. 1997a, 1997b, Servomaa & Tapiovaara 1998, Hansen et al. 2003, Helmrot et al. 2003, Osei et al. 2003).

PCXMC is a widespread and well tested Monte Carlo program for calculating a patient's organ doses and the effective dose in medical x-ray examinations (e.g. Hart 1997, Carlsson et al. 1999, Lampinen 2000, Mooney et al. 2000, Schmidt et al. 2000, Tapiovaara et al. 2000, Geijer et al. 2001, Kepler 2001, Papadimitriou et al. 2001, Tort et al. 2001, Dimov & Vassileva 2002, Spoelstra et al. 2002, Hansen et al. 2003). The anatomical data is based on the mathematical hermaphrodite phantom models of Cristy (1980), which describe patients of six different ages: newborn, 1, 5, 10, 15-year-old and adult patients. The height and weight of the patient can be set from a real patient. All organ doses calculated by PCXMC relate to the patient entrance air kerma (free-in air, without backscatter) at the point where the central axis of the x-ray beam enters the patient. The datum can be obtained by combining data on the examination techniques and the radiation output of the x-ray source or by using the surface dose or Dose-Area Product measurements of actual patient examinations. (Tapiovaara et al. 1997, 1999) This enables the calculation of the effective dose related to the x-ray field size and provides a technique for monitoring the collimation of the x-ray field, which is important in paediatric radiology because of the closer proximity of the sensitive organ (Gallini et al. 1992).

Still, there are many reasons making it difficult to estimate a foetal dose (Servomaa & Paile 1999). Perisinakis (1999) and Osei and Faulkner (1999b) found that the amount of urine in the urinary bladder influences the depth of the foetus from 4 cm to 10 cm during the first trimester, depending on the individual, the status of the bladder, and the maternal BMI. Figure 3 shows the effect of the foetus depth on the foetus dose as calculated by FetDose program (Osei et al. 2003).

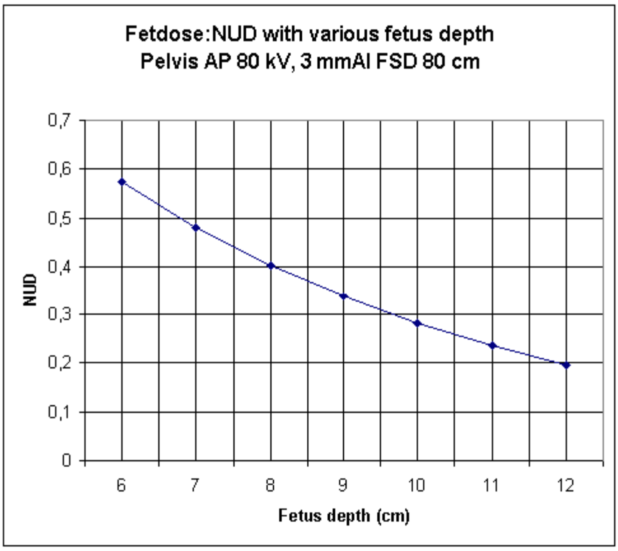

Figure 3. The effect of the depth of the foetus to the Normalised Uterus Dose (NUD) as calculated by FetDose program (Osei et al. 2003) during the first tremester (Servomaa & Kettunen 2004).

According to Tapiovaara et al. (1997), a change from 10 cm to 4 cm increases the dose of the foetus 3.1 fold when the foetus is in the primary beam (80 kV, 3.0 mmAl, FSD 80, 29x20 cm exposure area). Estimating the foetus dose at different depths by the FetDose program (Osei et al. 2003) agrees reasonably with Tapiovaara's et al. (1997) results. The foetal doses calculated by PCXMC and FetDose agree well with each other as Figure 4 shows (Servomaa & Kettunen 2004).

For an accurate determination of embryo depth, ultrasound measurement should be performed (Osei & Faulkner 1999b, Perisinakis et al. 1999). In indirect (outside beam of view) exposure, the distance between the foetus and the exposed area is a significant factor affecting foetal dose (Parry et al. 1999).

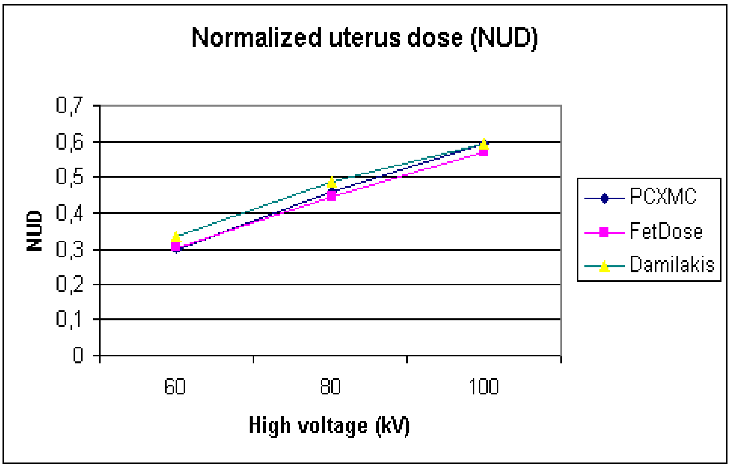

Figure 4. The comparison between Damilakis, PCXMC and FetDose in calculating the foetus dose when the foetus is in the primary field (Servomaa & Kettunen 2004).

2.8 Theoretical Background of this Study

The Council Directive 97/43/Euratom on the health protection of individuals against the dangers of ionising radiation in relation to medical exposure gives attention to the special protection requirements for childhood and during pregnancy because of higher radiosensitivity. The detriments of low-level radiation are becoming actual and discussion in this area is quite hot. The results of different studies are sometimes conflicting. However, there is consensus about the importance of radiation dose optimisation every time ionising radiation is used for medical purposes, especially with a foetus and children. There is also consensus about the higher cancer risk due to radiation among a foetus and children. According to the latest epidemiological studies (Hall 2004), there might be disturbance in intelligence after rather low radiation doses to the brain after birth. Further studies are required to prove these results. The radiation protection organisations and European Commission have published guidelines for the radiation protection of the foetus and newborns. Quality assurance programs and optimisation of the radiation dose must be carried out.

3 Purpose of this Study

The purpose of this study was to determine how the requirements set by degree 423/2000 of the Ministry of Social Affairs and Health to protect the most radiosensitive individuals are fulfilled by estimating the radiation dose and radiation risk to the foetus due to the x-ray examinations of an expectant mother and find out the practice of preventing the embryo and foetus dose and dose estimation practices in cases where the embryo or foetus are exposed. The second purpose was to estimate the radiation dose and risk due to the radiation to one special group: newborns treated in paediatric intensive care unit.

The following tasks were set down to achieve this goal:

1. Determine the number of x-ray examinations of the pelvis and lower abdomen performed on a pregnant woman in Finland
2. Determine the practice involved if the embryo or foetus has been or will be exposed due to x-ray examination of a woman of reproductive age

2.1 Determine the practice of excluding the possibility of pregnancy when conducting x-ray examinations of the pelvis and lower abdomen of women of reproductive age in Finland

2.2 Determine the practice of foetus dose estimation due to the x-ray examination of a pregnant woman

2.3 Determine the practice in guiding a pregnant woman if the foetus is or will be exposed

3. Estimate the dose and risk to one risk group: newborns in the PICU

3.1 Estimate the dose to a newborn from a bedside chest-x-ray examination in the intensive care unit

3.2 Determine the number of radiation x-ray examinations to each newborn in the study period retrospectively

3.3 Estimate the total dose to these newborns retrospectively

3.4 Estimate the risk due to the total dose to these newborns retrospectively

A proposal for guidelines for good practice in the x-ray examinations of the pelvis and lower abdomen of women of reproductive age in Finland are made based on these results in order to prevent the foetal dose. A proposal is given for the dose estimation of the foetus due to mothers x-ray examination.

4 Materials and Methods

This study consists of two different materials. The first study describes and documents the practice of excluding pregnancy in the pelvic x-ray examinations of woman of reproductive age in Finnish radiation departments. In addition, the practice for foetus dose estimation and responsibility for advising the expectant mother on the radiation risk to the foetus are described.

The other study describes the current level of doses to newborns during their first years of life retrospectively and the risk due to this dose.

These two areas are important because the risk due to the radiation exposure to foetus and children is higher than to adults or older people. The European Commission directive (Council Directive 97/43/Euratom of 30 June 1997) implemented in Finnish legislation by degree 423 of the Ministry of Social Affairs and Health, emphasises the protection of children and unborn children (Sosiaali- ja terveysministeriö 2000).

4.1 Materials

4.1.1 X-ray Examinations of Women of Reproductive Age

The first survey consists of a questionnaire (Appendix D) concerning the number and practice of pelvic x-ray examinations of women of reproductive age. It determines the practice of excluding the possibility of pregnancy in x-ray examinations of pelvis and abdomen. The recording system for x-ray examinations of pregnant women, including the possibility of recording the technical parameters of examinations made or possibly made during pregnancy was examined. The practice concerning the dose estimation of the foetus due to the intentional or accidental pelvic x-ray examination of a pregnant woman was asked. Enquiries were also made concerning the reactions of an expectant mother to the radiation risk to the foetus.

There are about 450 safety licences for x-ray examinations in Finland (Rantanen 2002). The same institute can have one or more licences. The questionnaire was sent to all (290) radiation safety officers responsible for the safe use of radiation in hospitals (district, central or university) and health centres all over Finland (only one questionnaire was sent to each institute). The names and addresses where taken from the radiation safety licensing registry of the Radiation and Nuclear Safety Authority (STUK) of Finland. The questionnaires were signed by a research professor from STUK and by a researcher. Prepaid answer envelopes were enclosed. The number of returned questionnaires totalled 174 (60%); one was returned uncompleted. The number of the acceptable questionnaires came to 173.

The questionnaires were returned from 124 (71.7%) health centres and 49 (27.1%) hospitals. Figure 5 shows that 33 (19.1%) hospitals were regional, 11 (6.3%) central and three (1.7%) were university hospitals. There were two (1.2%) institutions where the type of institution was not mentioned. In ten questionnaires, the radiation safety officer stated he or she was responsible for the safe use of radiation at two or more locations. In these cases, one answer referred to the practice at two or three health centres. The number of x-ray institutions, if seen this way, was 187. According to Servomaa (2003), 16% of radiation safety officers responsible for the safe use of radiation work in 2 institutions, 5% in three, 3% in four and 3% in 5–11 institutions.

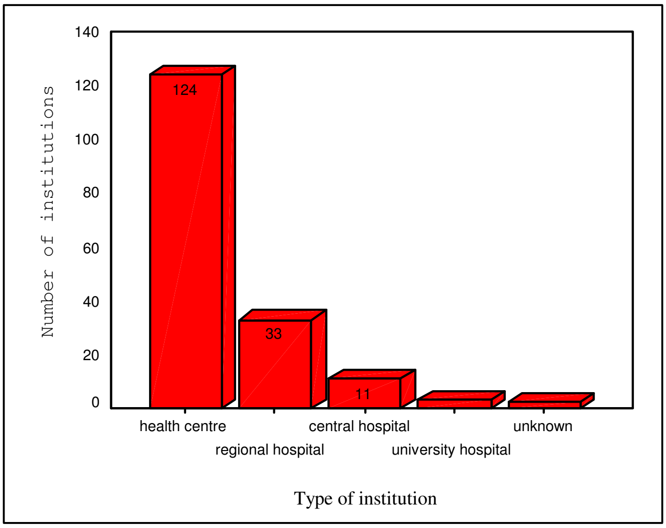

Figure 5. Type and number of institutions included in the study (n=173).

There were 114 (66%) respondents who reported some technical exposure parameters for x-ray examinations of the pelvis or lower abdomen (mostly pelvimetry). This information was mostly unusable because the dose could not be calculated due to the lack of mAs values (exposes were made using AEC). Two respondents provided information on real patient data documentation when a foetus was exposed in uterus.

4.1.2 Radiation Dose to Newborns

The doses due to the radiographic examination of bedside chests in the intensive care unit for newborns at Oulu University Hospital were studied; in 1998 there were 1641 x-ray examinations in the intensive care units for children and in 1999 there were 1819 (Kylmäniemi 2001). This data included 43 newborns treated in the paediatric intensive care unit. There were 118 chest examinations of 43 newborns in the intensive care unit at Oulu University Hospital at the beginning of 1998 (Group 1) and in the end of 1999 to the beginning of 2000 (Group 2). There were 27 premature infants. The gestational age in whole data varied from 26 to 42 weeks (Figure 6).

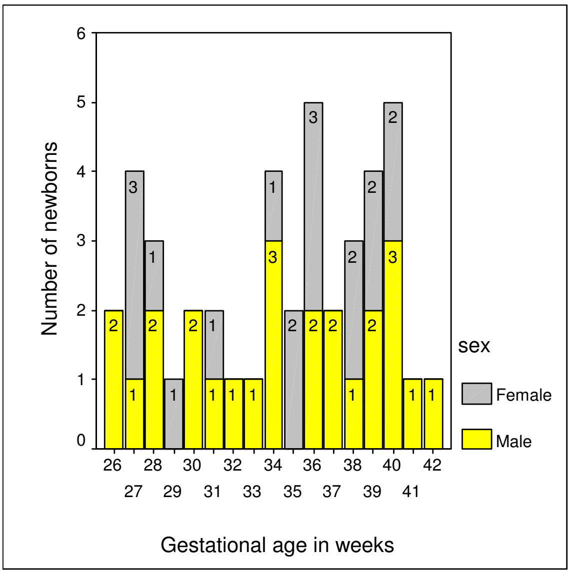

Figure 6. The sex and gestational age of the newborns in the data recorded (n=43).

There were 18 female and 25 male newborns with 118 bedside chest x-ray examinations in the data collected and their exposure factors were recorded. There were 67 (55.9%) chest ap examinations, 37 (31.4%) chest and abdomen ap and 14 (12.7%) chest and abdomen lateral radiographs of newborns (age up to 30 days) (Table IX). Originally, there were eight different bedside chest projections exposed in two paediatric intensive care units (because of the incubator). The attenuation of the incubator lid (9%) was taken into account in the dose estimation. The projections were combined into four groups: chest ap, chest and abdomen ap (from pharynx to hip joints), chest lateral and chest and abdomen lateral. These newborns were not exposed to chest lateral projection.

Radiographers with long experience in paediatric radiology produced the bedside x-ray examinations made in the PICU. The weight of the newborns varied from 0.660 kg to 5.060 kg (mean 2285 g) and their height from 31.5 cm to 57 cm (mean 43.5 cm) (Figure 7). The thickness of the newborns varied from 4.5 to 12.5 cm (mean 7.7 cm) in ap projections. The mean age of the newborns was 6.7 days (range from 0 to 35 days) at the moment of recorded exposure. The quality of the x-ray images was assumed to be high and good enough for making a diagnosis because experienced paediatric radiologists reported the images.

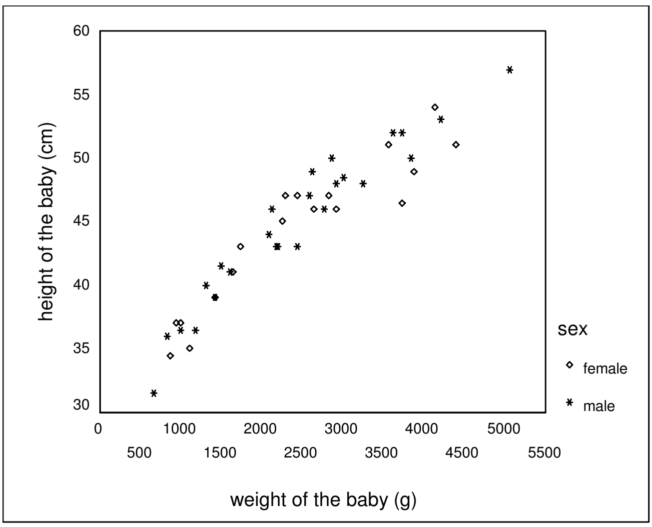

Figure 7. The height and weight of the newborns at the moment of exposure (n=118).

Retrospectively, the study showed that the total amount of radiological exposure for these 43 newborns during the study came to 399. Mostly, they were chest examination (345) made in the PICU during their first months of life. Some chest examinations (15) were exposed in another hospital after the baby was transported to the hospital for follow-up treatment. Other examinations given to them were hip joints (11 exposures), bone age (4 exposures), skull (4 exposures) and abdomen (30 exposures).

Table IX. The number of different chest projections and the weight of the newborns at the moment of exposure (n=118).

Weight (g)	Projection			
	Chest ap	Chest and abdomen ap	Chest and abdomen lateral	Total
500–1000	16	6		22
1010–1500	14	1		15
1510–2000	6	2	1	9
2010–2500	14	7	4	25
2510–3000	5	9	5	19
3010–3500	2	5		7
3510–4000	4	4	3	11
4010–5000	5	3	1	10
5010–6000	1			1
Total	67	37	14	118

4.2 Methods

4.2.1 Questionnaire Concerning the Practice of Pelvic X-ray Examinations of Women of Reproductive Age and the Radiation Dose to the Foetus Due to the Mother's X-ray Examinations

The questionnaire was based on a valid investigation form model prepared by STUK (Servomaa & Paile 1999) in order to record and estimate the foetal doses due to the x-ray examinations of a pregnant woman. The questionnaire included structured questions about the type of institute, the type and number of x-ray examinations of the pelvic region of women of reproductive age made in the department (questions 1, 3, 5) and the documentation of such x-ray examinations (question 2). It included questions concerning how the possibility of pregnancy is excluded (questions 2, 4, 12) and by who, when and how the estimation of the foetal dose (questions 6, 7, 8) is made. Questions were given regarding the way the information is given to the expectant mother about the radiation dose and radiation risk to the foetus (question 10). A question about the final decision-maker for the x-ray examination was added to the questionnaire (question 9). Question 11 dealt with the reactions of the expectant mother when she was told about the radiation risk to her baby. Question 14 included space for the technical parameters used in an x-ray examination when the uterus is in or near the exposure field. Question 15 gave the possibility to describe, with technical parameters, the documented situation in the plane, fluoroscopy and computed tomography examination of a pregnant woman. The questionnaire was tested by six radiation safety officers responsible for the safe use of radiation in different health care organisations.

The radiation dose to the embryo was calculated using PCXMC program (Tapiovaara et al. 1997) and the risk due to the dose to foetus by the FetDose program (Osei et al. 2003). The imaging technique and technical data was estimated from the data in ten questionnaires, from the study results of Hieta and Rautio (2000) concerning doses in lumbar spine x-ray examinations with different image receptors and from Kettunen (1996) concerning the dose in x-ray examinations of the chest, the hip joint and the pelvis. The data was analysed using the SPSS 11.5 statistical program (2002). The comments were analysed by simple content analysis (Kyngäs & Vanhanen 1999, Boyd 2001, Boyd & Munhall 2001, Latvala & Vanhanen-Nuutinen 2001).

4.2.2 X-ray Examinations of Newborns

Permission for the data collection was applied for from the ethical board of the Faculty of Medicine at the University Hospital of Oulu. The identities of the newborns were not recorded on the sheets. The x-ray examinations were made with an AMX-4 (GE Medical Systems) high frequency generator unit with 3 mmAl total filtration. Imaging plates of Agfa ADC MD-10 and MD-30 were used as image receptors. The plates were identical in their characteristic features and the same device was used to read them. The Dose-Area Product meter (DAP) was fixed in front of the x-ray tube. Data recording was carried out over two periods: January-March 1998 and November-December 1999 up to the beginning of January 2000. The times of data collection depended on the accessibility of the DAP meter. Summer was excluded because of the lack of the staff. The case histories of these 43 infants were analysed in 2001. Based on the case history and radiology form, the order of each x-ray examination in the collected data was determined and recorded on a sheet with the patient number. The total number of x-ray examinations was calculated and the total dose was estimated based on recorded data and earlier dose estimations made by STUK (Servomaa et al. 2000a, 2000b).

To improve the reliability of the study, the first data collection was made by one student radiographer and the latter by two radiographers. The data was documented during the daytime because there may have been radiographers from other units on other shifts and it would have been difficult to collect the data reliably. The radiographers recorded each examination and each patient on its own form, which included the date of the exposure, date of the child's birth, sex, height and weight. The data listed for the technique factors was projection (chest ap or lateral, chest and abdomen ap or lateral), whether the newborn was lying in an incubator, the thickness of the newborn, kV, mAs, the receptor-to-focus distance, use of the grid, exposure field size on the film and DAP. The Dose-Area Product meter system used in this study was VacuDAP 2001 with a sensitivity of $>8 \cdot 10^{-8}$ Gycm^2. It was compared with the DAP meter of the Radiation and Nuclear Safety Authority in Finland. The DAP reading was corrected by a conversion factor 0.9 if the baby lied in an incubator.

In this study, the ESD was calculated by the formula:

$$\mathrm{ESD\ (mGy)} = \mathrm{DAP(mGycm^2)}/\mathrm{A\ (cm^2)} \cdot \mathrm{BSF} \tag{4.2.2-1}$$

DAP is Dose-Area Product, A the exposure field size on the skin of the baby and BSF the Backscatter factor.

The backscatter factor (BSF) used for children's examinations varies from 1.1 to 1.36 depending on exposure factors, the patient's thickness and field size (Harrison 1983, Jones & Wall 1985, Tapiovaara 1985, Grosswendt 1990, Cranley et al. 1991, Schneider et al. 1992, Chapple et al. 1994, Wraith et al. 1995, Mooney & Thomas 1998). In this study, the BSF used was 1.15 for 60–78 kV with a field size of 50–330 cm^2. In other cases, when the tube potential was higher and exposed areas are wider, the BSF was 1.3.

The effective doses for the 118 examinations were calculated by PCXMC based on the Dose-Area Product reading. For the effective dose estimation, the skin-to-focus distance was calculated for each patient. The exposed area on the patient's skin was calculated separately by the known focus to image receptor distance and the thickness of the newborn (Kettunen 1996). The effective dose of the chest examinations with no documented technique was estimated based on the calculated doses to the same infant. The effective dose for other examinations (4 fluoroscopic examinations: 2 oesophagus, 1 barium meal and 1 passage and one nuclear medicine examination of bones) were estimated from data, based on Finnish practice, published earlier (Servomaa et al. 2000a, Servomaa et al. 2000b).

The wide range in children's sizes, even in infants and the effect of this on radiographic exposure factors, complicates comparing the dose (Gallini et al. 1992). There are several classifications for age groups used for children' dose comparison (Gallini et al. 1992, Martin et al. 1994, Kyriou et al. 1996, Office for Official Publications of the European Communities 1996, Schneider et al. 1998), but they were not suitable for this study. All the newborns were under one month of age in the data collection period.

The European Union has issued guidelines on the quality criteria for diagnostic radiographic images in paediatrics for the Entrance Surface Dose (ESD) for children under one month of age but there are no demands for the weight, height or thickness of the newborn. (Office for Official Publications of the European Communities 1996.)

The statistics for the examinations of the newborns were low. The data collection was made during two periods. The difference between these groups in height, weight and thickness of the newborns was studied. Logistic regression was used to find the factors affecting the effective dose of newborns in chest ap and chest and abdominal ap projections but not in lateral view because the group had only few observations. Multilinearity between the variances was studied (Altman 1991, Helenius 1995, Munro 1995). The correlations between the imaging technique, exposure area, doses or infant's size were studied using Pearson correlation factors.

5 Results

5.1 The X-ray Examinations of Pelvis and Lower Abdomen of Women of Reproductive Age

5.1.1 X-ray Examinations of Pregnant Women

The first questions concerned the statistics of the x-ray examinations performed on pregnant women. The number of x-ray examinations performed on a pregnant woman was not documented very well, except for x-ray pelvimetry examinations. In 1999, 25 x-ray examinations of bones (extremities) and sinuses, one fluoroscopy and two CTs (one in each place) were carried out on pregnant women in eight institutions out of 173. In addition, there were pelvimetry x-ray examinations in 26 institutions, all together 2173 examinations on pregnant women. To the question "how many x-ray examinations of the pelvis and abdomen were made to a pregnant woman in your hospital" produced a great number of the respondents' comments concerning uncompiled statistics (38 comments), no need for x-ray examinations of a pregnant woman in a health centre (55 institutions) or pregnant patients are sent to hospital (11 health centres).

"the question and the answer are theoretical because statistics are compiled only for pelvimetry x-ray examinations"
"in a health centre there is no need to x-ray a pregnant woman"
"if the patient is pregnant, she is sent to the central hospital (from a regional hospital and health centres)"
"don't know if such examinations have been performed"

52 % (90 places) which stated that no x-ray examinations been made of the pelvic or abdominal region of a pregnant woman, 19.7% (34 places) did not document them and 28.3% (49 places) did not answer the question at all. In 48% of these institutions, the situation was uncertain as to whether x-ray examinations to a pregnant woman had been performed.

X-ray pelvimetries are taken in health centres and in hospitals. Some hospitals only carry out MRI pelvimetry. The number of pelvimetry x-ray examinations varies widely from four examinations a year in some places up to more than two hundred; the mean was 79.7 examinations (Table X).

Table X. The x-ray pelvimetry examinations performed in different institutions in 1999 in this study (n=26).

Type of institution	**Number of places** **n**	**Total number of x-ray pelvimetries** **n**	**Range** **n**
Health centre	4	265	4–105
Regional hospital	14	995	4–234
Central hospital	7	701	15–228
University hospital	1	212	212
Total	**26**	**2173**	

5.1.2 The Documentation and Exclusion of the Possibility of Pregnancy in Pelvic X-ray Examinations of Women of Reproductive Age

The radiographer has to check the possibility of pregnancy before the x-ray examinations of pelvis and lower abdomen of women of reproductive age. Table XI shows that in 61 (49.2%) *health centres*, the most common way of excluding the possibility of pregnancy was to ask a woman of productive age whether she was pregnant. In 18 cases (14.5%), the referring physician asked the same question. Other ways were the 10 days rule with 14 (11.3%), pregnancy test as routine 9 (7.3%) and in the same range the use of a reliable contraceptive (pills, IUD or sterilization). In three institutions (2.4%), a poster on the wall was the only way of checking the possibility of pregnancy. Two health centres (1.6%) have a preliminary guide and in one case, patients fill in a written form. Three respondents (2.4%) stated that there was no need to check the possibility of pregnancy "because patients are nowadays very aware". Most health centres 86 (69.4%) commented on other practices to check the possibility of pregnancy: "if there is something unclear or the patient is unsure". In these cases, the most important way was to give a pregnancy test (28.2%); other important ways are posters on the wall (9.7%) and an interview made by the radiographer before the x-ray examination of the pelvic region.

Table XI. The methods of checking the possibility of pregnancy in different types of institutions.

Excluding possibility of the pregnancy	Health centre		Regional hospital		Central hospital		University hospital		Unknown		Total	
	Main	Second	Main	Second	Main	Second	Main	Second	Main	Second	Main	Second
	n	n	n	n	n	n	n	n	n	n	n (%)	n (%)
No answer	4		1								5 (2.9)	
Physician asks	18	1	4		1				2		25 (14.5)	1 (0.6)
Pregnancy test	9	35	2	4	1	1					12 (6.9)	
Radiographer asks before examination	61	13	15	5	6	1	3				85 (49.1)	19 (11.0)
Contraception	9	11	1	4							10 (5.8)	15 (8.7)
Asked in written form	1	1									1 (0.6)	1 (0.6)
Posters on the walls	3	12	6	3	1	2		1		1	7 (5.8)	19 (11.0)
Patient is responsible		2		1								3 (1.7)
No need to ask	3										3 (1.7)	
10-day rule	14	7	2	1							16 (9.2)	8 (4.6)
Asked on enrolling		2	2	6		3		1			2 (1.2)	12 (6.9)
In preliminary guide	2	1		1	2						4 (2.3)	2 (1.2)
In appointment		1				1						2 (1.2)
All	124	86	33	25	11	8	3	2	2	1	173 (100)	122 (70.5)

In 15 *regional hospitals* (45.5%), the most important way of excluding the possibility of pregnancy was the radiographer's question before the examination about whether the patient was pregnant. In six institutions (18.2%), they had posters on the wall or they trusted that the referring physician had found if the woman was pregnant. The ten-day rule was in use in two institutions. The same range was in having a pregnancy test and asking about the possibility of pregnancy when the patient is registering for an x-ray examination.

In all three *university hospitals* and six *central hospitals* (54.5%) the radiographer interviews the patient about the possibility of pregnancy before an x-ray examination. A pregnancy test, trusting the physician and a poster on the wall are used in one place in each central hospital. Two hospitals (18.2%) have a preliminary guide to give advice on these situations. The unspecified institutions trust a physician's decision. Five respondents (2.9%), (one regional hospital and four health centres) did not answer this question at all**.** There are no differences in the practices between hospitals and health centres as seen in Figure 8.

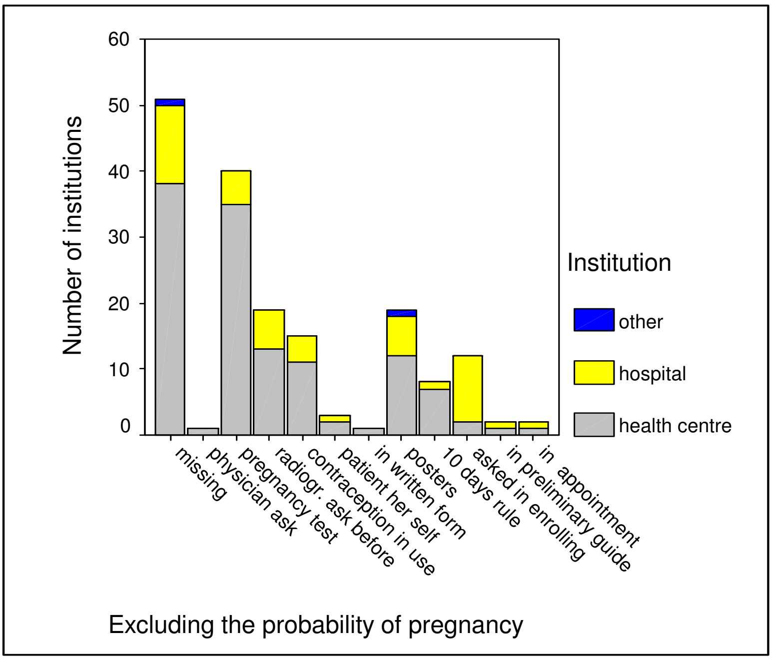

Figure 8. The manner of excluding the probability of pregnancy in health centres and hospitals.

The question concerning the age a woman should be asked whether she is pregnant produced 40 different alternatives. Four respondents did not answer this question. There were 142 institutions that had two or more other ways as the same alternative. The possibility of pregnancy was checked in 17.6% of the departments (25 out of 142) and institutions (21 health centres, 1 each from the other groups) with women aged from 15 to 50 years. In 12.7% (18 out of 142, 13 health centres, 4 regional hospitals and 1 central hospital), they asked the possibility of pregnancy if the woman was between 15 and 45 years of age. 11.3% (16 out of 142, 7 health centres, 6 regional hospitals, two central and one university hospital) stated that they check the possibility of pregnancy with patients less than 50 years of age and 9.2% with women less than 45 years of age (13 out of 142, 11 health centres and one regional and central hospital). Females of "fertile age" were asked if they were possibly pregnant in 8.5% of the institutions (12 out of 142, 6 health centres, 3 regional, 2 central and 1 university hospital). Women aged 21 to 40 years were asked about the possibility of pregnancy in 6.3% (9 out of 142, 8 health centres and one central hospital) and women aged 16 to 45 in 5.6% (8 out of 142, 4 health centres, 3 regional and 1 central hospital). In 4.9% (7 out of 142) of health centres, they checked the possibility of pregnancy if the patient was between 14 and 50 years. 3.5% (5 out of 142, 2 health centres and 3 regional hospitals) asked it a 17 to 50 year-old patient if she was pregnant. In 2.8% (4 out of 142, 3 health centres and 1 regional hospital), no one was asked the question. In other cases, there were three places each. In the rest, 31 of the 173 institutions, there were 19 different versions. The lowest age was 12 years in 4 places, 13 years in 3 institutions and 20 years in one department. The upper age varied from 35 to 55 years. The respondents from health centres and regional hospitals commented:

"if the patient is pregnant or the situation is complicated, the patient will be sent to the central hospital"
"It is the duty of the referring physician to ensure whether the patient is pregnant".

In 116 institutions (N=173), no documentation was made of whether the possibility of pregnancy had been excluded before the x-ray examination of the pelvic or abdominal area of a woman in fertile age. Thirteen respondents did not answer this question. Figure 9 shows that of those 44 who documented the presence of pregnancy, 65.9% (29 out of 44) wrote a comment (no pregnancy, date of last menstruation) in referral, and 11.4% (5 out of 44) in the case history (in electronic or paper form). Two institutions (out of 44) had separate form where the patient herself gave information on the possibility of pregnancy. The remaining 6 institutions (out of 44) commented in the referring or case history on whether the patient was, or probably was, pregnant. Most of the respondents had never faced a situation when only afterwards was it noticed that the patient was pregnant when having an x-ray examination.

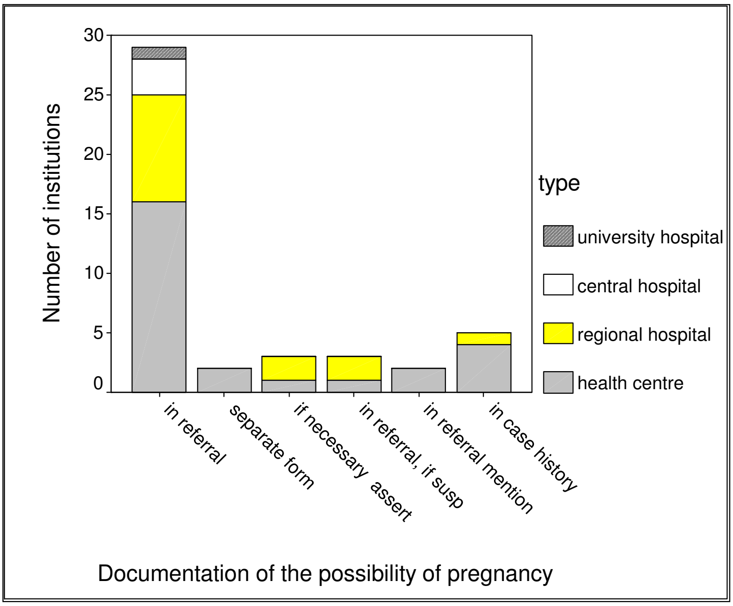

Figure 9. The manner of documenting the possibility of pregnancy in different types of institutions (n=44).

5.1.2.1 Poster for Woman of Reproductive Age

Most of the institutions have a poster on the walls of waiting and/or dressing rooms:

"If it is possible that you are pregnant, please notify the physician or radiographer before your x-ray examination" (International Commission on Radiological Protection 84, 2000).

There are no posters at all in 12 health centres and two regional hospitals. In some cases, the reason why was explained:

"We had one earlier, but we took them away because all men said they were not pregnant"
"no need for them because patients are so well aware"

5.1.3 Estimation of the Foetal Dose

About 80% (139 out of 173) stated that they have never been in such a situation where they noticed that the patient was pregnant at the moment of exposure after having given an x-ray examination of the pelvic or abdominal region (Table XII). The respondents from 87 health centres commented:

"*don't get any feedback if such situations exist*"

If an x-ray examination of the pelvic or abdominal region had been made to a pregnant patient, the dose to the foetus was evaluated in 14.5% (25 out of 173) of the institutions. In 58 institutions, the estimation was not made and in five institutions, they believed that there was no need for estimating the foetus dose.

26.6% (46 out of 173) of the respondents answered the question of who makes the dose estimation. Figure 10 shows that radiologists in all types of institutions mostly make the estimation. Only in four cases does physicist make the estimation. The referring physician makes the estimation of the foetal dose in 11 health centres. One regional hospital and two health centres ask STUK for help.

Table XII. The number of cases where the patient was pregnant during the x-ray examination of the pelvic region and the pregnancy was discovered after the examination.

	Health centre	Regional hospital	Central hospital	University hospital	Unknown	Total
	n	n	n	n	n	n (%)
Once a year	8	0	2	3		13 (7.5)
Less often	6	4	1			11 (6.4)
Never	104	26	8		1	139 (80.3)
No answer*)	6	3	0		1	10 (5.8)
Total	**124**	**33**	**11**	**3**	**2**	**173 (100)**

*) no answer received

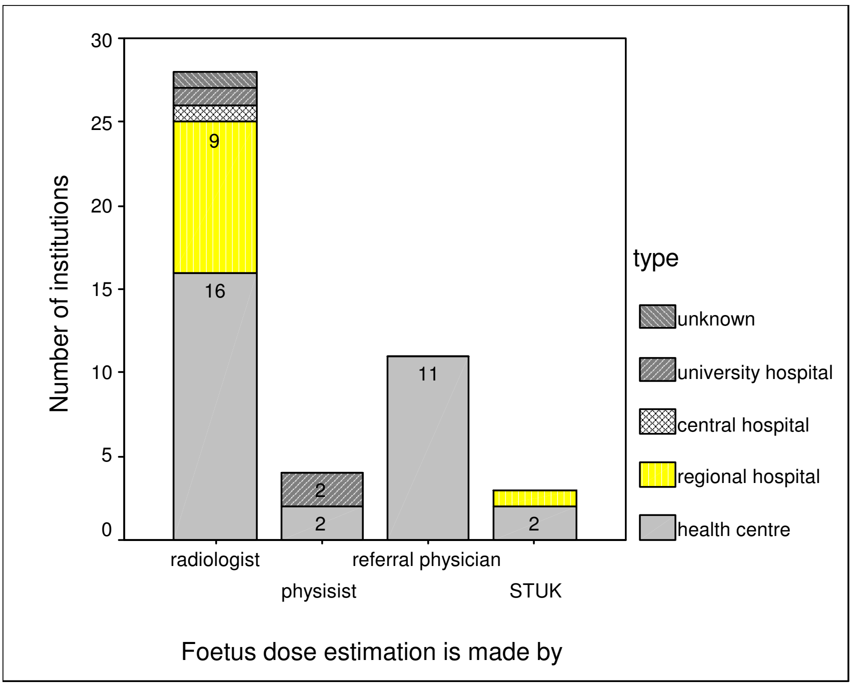

Figure 10. The main estimator of the foetal dose in different types of institutions (n=46).

There was more than one person in 18 (39.1% of 46) places who made the foetal dose estimation. Table XIII shows that in five places the radiographer was responsible for the dose estimation together with the referring physician and in four cases with radiologists. Radiologists and physicists were jointly responsible in five cases.

Table XIII. The number of places where the foetal doses were estimated by more than one estimator (n=18).

	Radiolo-gist	**Physi-cist**	**Referring physician**	**Radio-grapher**	**STUK**	**Total**
	n	**n**	**n**	**n**	**n**	**n**
Radiologist		5	2	4		11
Physicist					1	1
Ref. physician				5		5
STUK	1					
Total	**1**	**5**	**2**	**9**	**1**	**18**

When the pelvic or abdominal region x-ray examination of pregnant woman was needed, the dose estimation of the foetus was made in 25.4% of the institutions. More than half respondents (56%) did not answer this question and in addition, 14.5% stated that estimation was not made.

Figure 11 shows the timing of dose estimation and type of institution where it was made. The foetal dose was estimated in 19.1% of the institutions *before* the pelvic or abdominal x-ray examination of a pregnant woman. The foetal dose estimation was made in seven (4% out of 173 cases) institutions *after* the pelvic or abdominal x-ray examination of a pregnant woman: in three health centres, one regional, one central and two university hospitals. In two regional and two central hospitals, foetal dose estimation was made if the patient asked for it. In one health centre and one regional hospital, the dose estimation was made if required e.g. if the referring physician required it. The respondents from four health centres and one central hospital stated that there was no need for estimation. In two health centres and one regional hospital, the foetal dose was estimated *both before and after* the pelvic or abdominal x-ray examination of a pregnant woman.

The most important way of estimating the foetal dose was to use literature (61.4%) or estimation based on imaging technique (20.5%) and a dose calculation program (e.g. DAP and PCXMC) (Table XIV). In two cases, TL dosimeters or a phantom were used. The remaining the respondents made the estimation “based on experience” or “feeling” (it feels like this).

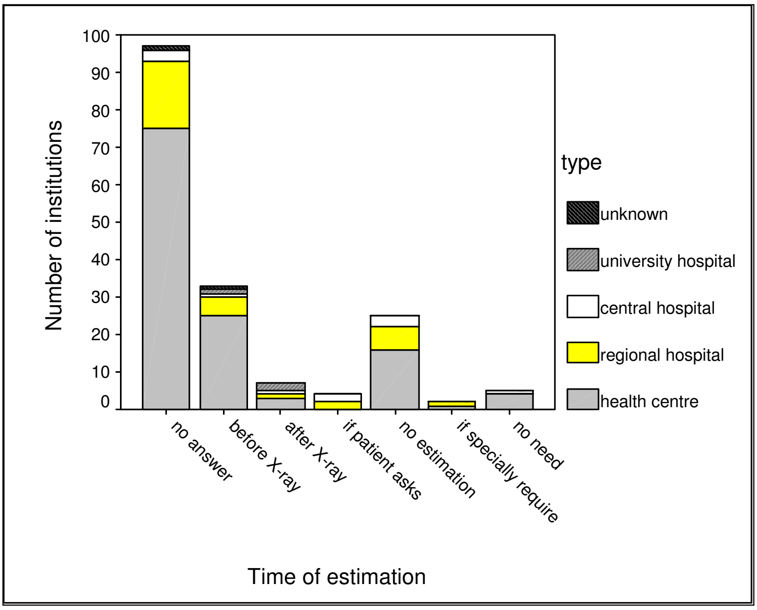

Figure 11. The timing or situation of the foetal dose estimation and type of institution (n=173).

Table XIV. The methods used for the foetal dose estimation in different institutions (n=44).

	Health centre	**Regional hospital**	**Central hospital**	**University hospital**	**Unknown**	**Total**
	n	**n**	**n**	**n**	**n**	**n** *)
Literature	16	6	2	2	1	27 (15.6/61.4)
Estimation	4	3	1	1		9 (5.2/20.5)
Measuring	1	1				2 (1.2/4.5)
Experience	2		2			4 (2.4/9)
No need	1					1 (0.6/2.3)
"Feeling"	1					1 (0.6/2.3)
Total n **)	**25 (20.2)**	**10 (30)**	**5 (45.5)**	**3 (100)**	**1 (50)**	**44 (25.4/100)**

*) n (% of total 173 case/% places where estimation was made)

**) n (% of the group/% cases where estimation was made)

5.1.4 The Decision-Making Process for Performing X-ray Examinations of Pregnant Women

The question of the decision for the need of x-ray imaging a pregnant woman in different institutions was answered by 93.1% of the institutions (161 out of 173; 8 health centres and 4 regional hospitals didn't give any comment). As seen in Table XV, in the health centres the referring physician made the decision for x-ray examination in 66 cases and the physician and radiographer jointly made the decision in 12 cases. Radiologist and physician or patient and physician jointly made the decision in 10 places (8.6%) and physician, patient and radiographer together in 8 (6.9%) cases. In six health centres, radiologists made the decision for the x-ray examination of a pregnant woman; in regional hospitals, the corresponding share was 11 (37.9%) out of 33 and in central hospitals, it was 2 (18.2%) out of 11 cases and in university hospitals it was 1 out of 3 cases. The other decision-makers in regional hospitals were the physician in 6 (20.7%) out of 33 cases and radiologist and physician together in 5 (17.2%) out of 33 cases. In central hospitals, the radiologist and physician made the decision together in 5 (17.2%) out of 11 cases. In university hospitals, the remaining two used the radiologist and physician or the radiologist, physician and physicist.

Table XV. The decision-maker for the x-ray examination of a pregnant woman in different institutions (n =161).

Decision maker	Health centre n	Regional hospital n	Central hospital n	University hospital n	Unknown n	Total n (%)
Physician and radiographer	12		1			13 (8.1)
Radiologist and physician	10	5	5	1	2	23 (14.3)
Physician, patient and radiographer	8	3				11 (6.8)
Patient	1		1			2 (1.2)
Physician	66	6	2			74 (46.0)
Radiologist	6	11	2	1		20 (12.4)
Physician, radiologist and radiographer	1	2				3 (1.9)
Patient, physician and radiologist	1	2				3 (1.9)
Radiologist, physician and physicist	1			1		2 (1.2)
Patient and physician	10					10 (6.2)
Total (n)	**116**	**29**	**11**	**3**	**2**	**161**

In health centres, the referring physician made the decision and in unclear cases, the patient was sent to the central hospital. In hospitals, the practice was clear during office hours but in casualty time, the radiographer took responsibility for the decision. There were many comments and explanations in the answers that show how complicated the situation is:

"if the physician is present, he makes the decision; in other cases, the patient and radiographer together"
"The radiologist is asked during office hours; in casualty time, the radiographer makes the decision on whether to take an x-ray examination"
"The physician with the trauma patient and the radiologist of the x-ray examination of the pelvic region and CT and fluoroscopy examinations"
"Not done to a pregnant patient if the pregnancy is known"
"The radiologist asks the opinion of physician; in casualty time, it's the radiographer"
"In casualty time, a phone conference: physician - radiologist"

“Problematic cases are sent to the central hospital”
“The radiographer asks the patient if the referring physician is aware of the pregnancy; if no, the patient is sent back to physician”
“The x-ray examination will be done later, if possible”
“If the patient refuses, you can’t force her to have an x-ray examination”
“Physician = gynaecologist”
“The physician, at least in principle”
“The radiographer explains the danger of x-rays; the patient and physician make the decision!”
“Have a discussion: physician-radiographer-patient“

5.1.5 Radiation Dose and Radiation Risk to the Foetus Due to the Mother’s Pelvic or Abdominal X-ray Examination

The foetal doses and risk to the foetus from the most common x-ray examinations of pelvis and lower abdomen are displayed in Table XVI. The doses were calculated using the PCXMC 4.1 program (Tapiovaara et al. 1997) and the risk due to radiation was calculated using the FetDose (Osei et al. 2003) program**.** The patient was assumed to be 165 cm tall and 65 kg in weight. The imaging technique was taken as the average data from the questionnaire sent to the radiation safety offices and from the studies by Hieta and Rautio (2001) and Kettunen (1996).

The radiation risk to the foetus increases linearly with the radiation dose (Figure 12).

Table XVI. Average foetus doses and risks in x-ray examinations of the pelvis and lower abdomen of a pregnant woman.

Examination	**Exposure parameters kV/mAs/ FSD**	**Air kerma mGy**	**Foetal dose mGy**	**Ovaries dose**	**Red bone marrow mGy**	**Hereditary effect 10^{-5}**	**Fatal Leukaemia 10^{-5}**	**Fatal cancer 10^{-5}**
LS-spine AP	75/60/95	4.5	1.67	1.19	0.073	5.0	1.6	2.2
LS-spine lat	85/160/80	22.0	1.03	1.69	0.68	1.2	0.6	1.0
LV lat	90/200/80	23.8	1.36	1.71	0.72	2.4	1.2	1.8
Pelvis AP	70/80/95	5.1	1.92	1.40	0.20	4.4	2.2	3.0
Hip AP	70/60/95	3.0	1.04	0.71	0.10	1.2	0.6	1.0
Abdomen AP	85/40/90	4.1	1.81	1.51	0.24	5.6	1.9	2.6
SI-joint AP	70/60/90	3.4	1.22	0.80	0.078	2.4	1.2	1.8
Coccyx AP	75/80/90	5.2	1.91	1.15	0.085	4.4	2.2	3.0
Pelvimetry Lat	90/250/90	23.5	1.77	2.35	0.93	5.6	1.9	2.6
Urography AP kidneys	70/80/90	4.5	1.68	1.07	0.16	5.0	1.6	2.6

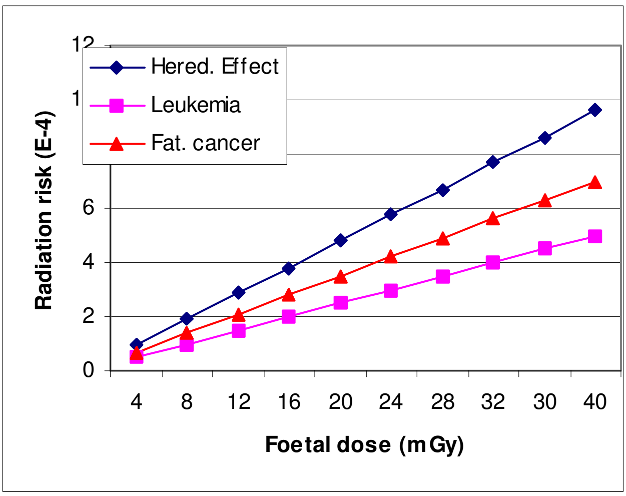

Figure 12. The radiation risk for hereditary effects, leukaemia and fatal cancer with different doses estimated using the FetDose program (Osei et al. 2003).

5.1.6 Information to an Expectant Mother about the Radiation Risk to the Foetus Due to Ionising Radiation and the Mother's Reaction

The possibility of harm or detriment to the foetus due to x-rays was explained to the expectant mother by the physician in 18.4% (29 out of 158) or by the physician and radiographer together in 41.8% of the institutions (66 out of 158). The physician together with the radiologist and radiographer explained it in 17.1% (27 out of 158) of the institutions. In 8.9% cases (14 out of 158) the radiographer, in 6.3% (10 out of 158) the physician and the radiologist together and in 4.4% (7 out of 158) the radiographer and the radiologist explained the risks to the expectant mother. The midwife or a registered nurse explained the risks in 1.3% (2 out of 158) of the cases and nobody explained them in 1.9% (3 out of 158) of the cases. In health centres, the explanation was given by either the referring physician or the radiographer or both together. (Table XVII).

Table XVII. The explainer of the risks due to the x-rays to the expectant mother in different institutions (n= 158).

Explainer	Health Centre n	Regional hospital n	Central hospital n	University hospital n	Unknown n	Total n (%) of type
Physician	27	2				29 (18.4)
Radiographer	9	5				14 (8.9)
Midwife/nurse	2					2 (1.3)
Nobody	2	1				3 (1.9)
Physician? and radiographer*)	60	4	2			66 (41.8)
Physician, radiologist and radiographer	9	11	5	1	1	27 (17.1)
Radiographer and radiologist	2	4	1			7 (4.4)
Physician and radiologist	2	3	2	2	1	10 (6.3)
Total	**113**	**30**	**10**	**3**	**2**	**158**

*) In Table XVII the question mark after the “physician and radiographer” means that these 60 answers included comments like
“physician? or hopefully physician; don’t know” (in 50 questionnaires)
“no agreement on the practice; physician should, don’t know what the physician discusses with the patient” (in 20 questionnaires)
“haven’t discussed the practice” (in ten questionnaires)

There was also one comment concerning fluoroscopic examinations
“In fluoroscopic examinations or if the patient is pregnant, the radiologist is responsible for advising about the risk”

Three respondents answered that if the patient asked, the radiographer explained; in other cases, nobody explained. In one university hospital, written material about the practice was planned for patients and for physicians.

There was very little experience among the respondents on how a pregnant woman reacted when she was told about the radiation dose to the foetus and the risk due to the ionising radiation (Table XVIII). There were 21 (20.2%) respondents who had no experience of such a situation (the alternatives were from 84 institutions, 48.6% of 173 cases). The most common reaction was that the patient wanted more knowledge (46 cases). The next were that the patient was frightened (24 cases) or accepted the risk (9 cases). Most of the respondents pointed out that the answers they had given were quite theoretical and they had no experience of real situations.

Table XVIII. The reaction of an expectant mother when she was told about the radiation dose and radiation risk to the foetus.

Patient’s reaction	Health centre n	Regional hospital n	Central hospital n	University hospital n	Other n	Total n
Gets a fright	12	10		2		24
Gets anxious	1					1
Wants more information	35	8	2		1	46
No reaction	1					1
Wants an abortion	1					1
Accepts the risk	3	4		2		9
Don’t want the exam	2					2
Depends on individual		1	1	1		3
No answer	54	10	4		1	69
Total	**108**	**34**	**9**	**3**	**2**	**156**

87.9% (152 out of 173) of the institutions (109 health centres, 30 regional, nine central and three university hospitals and other of unknown types) have a poster on the wall of the waiting or changing room (or both): “If you are or probably are, pregnant, please, notify the staff before your x-ray examination”. Five (2.9%) respondents did not answer. There are no posters in 12 health centres, two regional and two central hospitals.

In 30.1% of the institutions, the x-ray examination of a pregnant woman was always changed to ultrasound, if it was possible. “There is no need for change” in 8.1% of the institutions, and 6.9% (12 health centres or regional hospitals) sent a pregnant patient to the central hospital. 43.4% of the respondents did not give any answer.

5.2 The X-ray Examination of Newborns

5.2.1 Chest X-ray Examinations of Newborns in the PICU

There were 118 chest examinations made to 43 newborns in the intensive care unit of Oulu University Hospital in the beginning of 1998 (Group 1) and at the end of 1999 (Group 2) up to beginning 2001. One pair of twins and two B-parts of twins (baby B is born later than baby A) were included in the data. There were 66 chest ap, 37 chest and abdominal ap and 15 chest and abdominal lateral projections. Lateral chest projections were not performed.

The smallest newborn in weight was 660 g at the moment of exposure. The weight of the newborns at the moment of exposure, sex and projections are seen in Table XIX.

The chest and abdominal ap was always taken when the newborn had its first chest x-ray and the chest and abdominal long lateral mostly at the same exposure time. The chest and abdominal projections are usually taken later only when the paediatrician requests it in order to evaluate the condition of the infant’s abdominal region. The indication for chest and abdominal projection was rarely seen in the diagnosis written in the patient record. Figure 13 shows the order of the recorded chest and abdomen exposure.

Table XIX. Examination projections, sex and weight of the newborns at the moment of exposure.

Weight (g)	Projections: Chest ap Female/Male n	Chest and abdom. ap Female/Male n	Chest and abdom lateral Female/Male n	Total Female/Male n
500–1000	9/8	5/1	-/-	14/9
1001–1500	5/9	0/1	-/-	5/10
1501–2000	1 /5	1/1	-/1	2/7
2001–2500	10/4	4/3	2/2	16/9
2501–3000	1/3	5/4	2/4	8/11
3001–3500	-/ 2	4/1	-/-	4/3
3501–4000	1/3	3/1	2/1	6/5
4001–4500	2/2	2/1	1/-	5/3
4501–5000	-/-	-/-	-/-	-/-
5001–5500	-/ 1	-/-	-/-	-/1
Total n	29/37	24/13	7/8	60/58

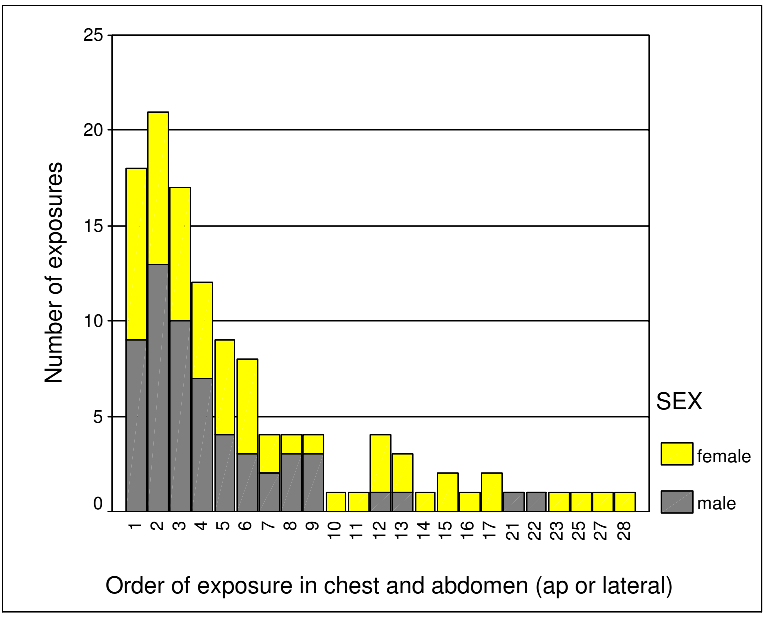

Figure 13. The order of the exposure of the chest and abdomen (ap or lateral) projections to the newborns (n=54).

The main diagnosis (mentioned first in the patient record) to 23 newborns (53.5%) was “premature infant” and to three newborns “RDS” (7%). The remainder had different diagnoses such as “toxaemia matris” or “small weight at birth”. The second diagnosis for 19 newborns (73.1% out of 26 cases) was “RDS” and 18 of them had “premature infant” as the main diagnosis. These 23 premature infants were given 18 chest and abdomen ap and 5 chest and abdomen lateral projections.

As seen in Figure 14, in 43 (36.4%) examination time the newborn needed help with breathing and were intubated at the moment of exposure of the chest ap and in 24 examinations (28.3%) when having a chest and abdominal ap. The indication for 13 chest x-rays (15.3%) was “extubation” (tube was taken away and after that the chest ap was performed).

5.2.1.1 The Imaging Technique for Chest X-ray Examinations of Newborns in the PICU in the Recorded Data

The images were produced with a mobile AMX-4 machine. The focus-image receptor distance was always 1m, total filtration was 3 mmAl and no grid was used. The tube voltage in the chest ap projections varied from 66 kV to 80 kV (mean 69.2 kV) (Figure 15). The thickness of the newborns in ap projections varied from 5 cm to 15 cm (mean 7.7 cm) when measured by special equipment (a ruler with branch) at the same time as the exposure was made. In chest-lateral (n= 15) the tube potential was from 70 kV to 74 kV (mean 71 kV).

The tube voltage (kV) varied by 6 kV in ap projections taken of babies with the same thickness.

The weight, height and thickness of the newborns having chest ap or chest and abdomen ap projections showed significant correlation (Figure 16). The correlation in all the data is between weight and height is r=.938, and between the thickness and weight of the neonate r=.739. There was no difference between sexes. The tube voltage (r=.808), the mAs-value (r=.657) and the thickness (r=.623) of the baby correlate positively.

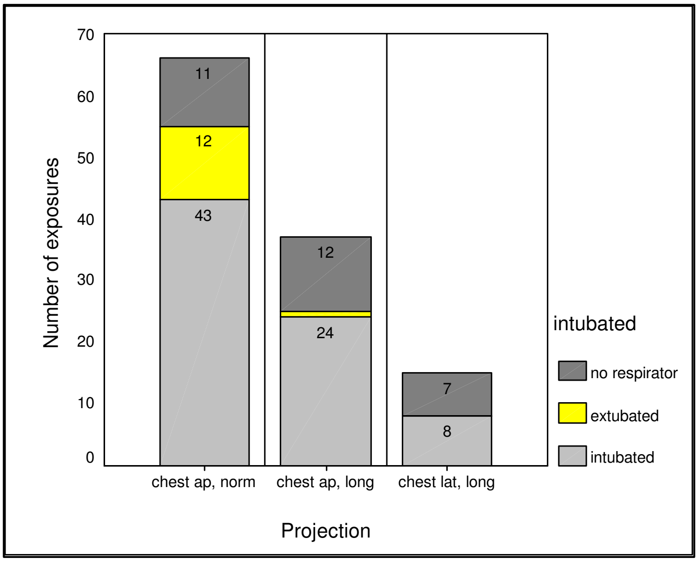

Figure 14. The projections and number of chest aps to newborns and the intubation of a newborn at the moment of exposure (n=118).

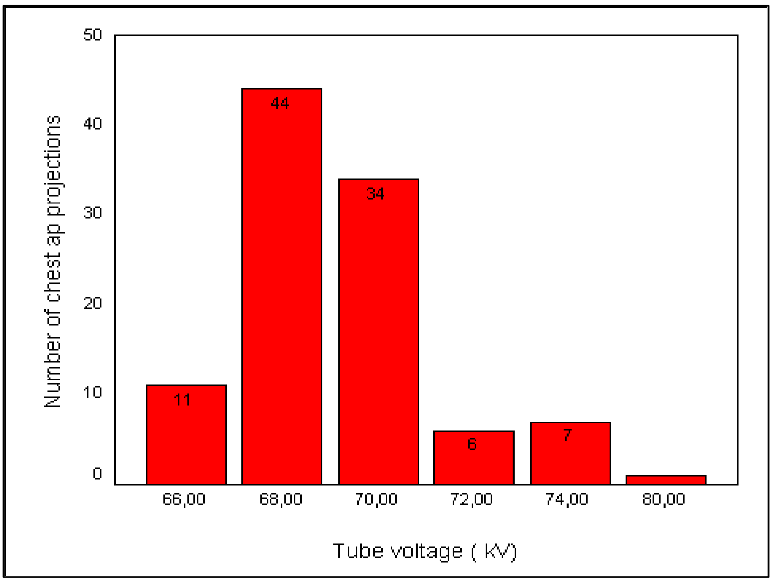

Figure 15. Tube voltage (kV) in chest ap projections (n=103).

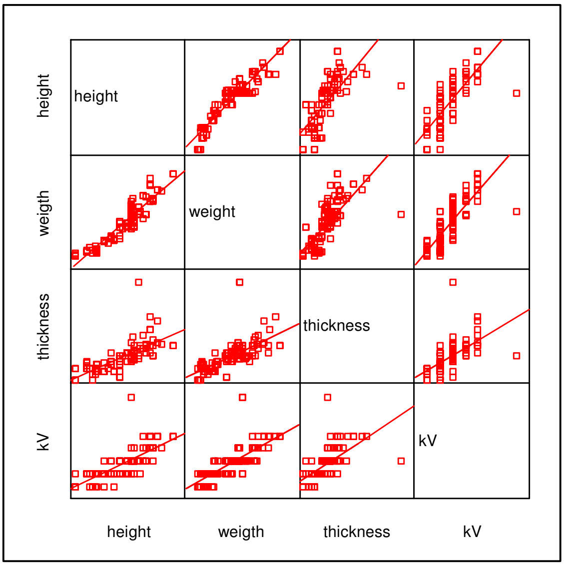

Figure 16. The qualitative correlations in the height (cm), weight (cm) and thickness (cm) of the baby and tube voltage (kV) in chest ap and chest and abdominal projections (n=103).

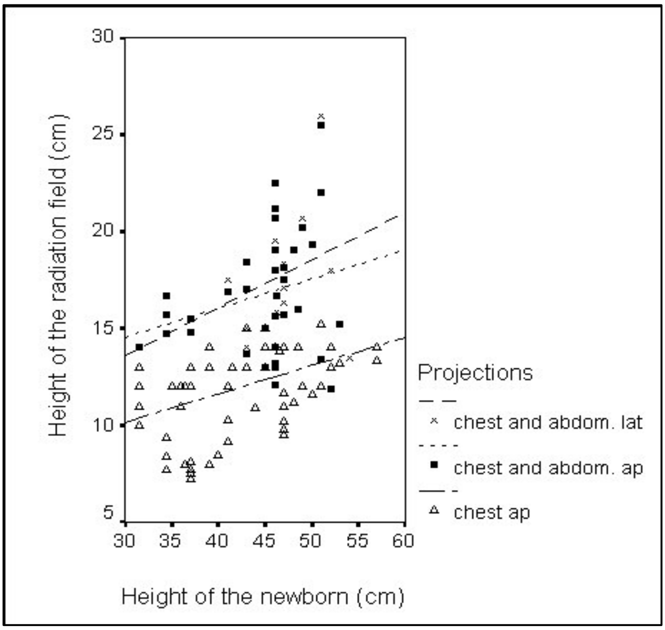

Figure 17. The correlation of the height of the exposure field in different projections and the height of a newborn (n=118).

The height of the exposure field correlates with the height of the newborn lightly (r=.433) in the whole data. The correlation between the same parameters in chest aps was r=.422 but in chest and abdomen aps r=.262. The heights of the exposure fields for newborns with the same height inside the same projection differed by 10 cm (Figure 17), especially in chest and abdomen ap.

5.2.1.2 The X-ray Examinations of Small Infants

There were 72 chest exposures to newborns under 2500 g in weight. The weight of these newborns varied from 660 g to 1740 g (mean 1657 g) and their height varied from 31.5 cm to 43 cm (mean 40 cm). There were made from two to 23 x-ray examinations to each infant (mean 9.5 exposes). There were 13 male and 10 females. They had 51 chest ap, 16 chest and abdominal ap and 5 chest and abdominal lateral x-rays. The gestational age was from 26 weeks to 39 weeks; the mean was 30 weeks. They were mostly the first or second children in their family, but the range was from first (8 newborns) to 14^{th} in order; the mean was 2.9. One third of the ap projections were chest and abdominal projections.

If the group of the small newborns *under 2000 g* was examined separately, there were still 15 newborns, eight male and seven female, left. Their gestational age varied from 26 to 36 weeks (mean 28.8 weeks); in 14 (n=15) cases it was under 32 weeks. Five of them were the first and four the second, one was the 14^{th} (mean 3.27) child in the family. There were 169 x-ray examinations made to them, ranging from 2 to 21 examinations (mean 11.3 exposures). Three quarters of the x-ray examinations were chest and abdominal projections, which differs from the group of newborns less than 2500 g in weight. The reason for this was unclear. The height of the exposure field in the same projection and the same height of the newborn could differ from 3 cm up to 7.8 cm.

5.2.2 The Doses to the Newborns in the PICU

The *ESD* (Entrance Surface Dose) was estimated by calculating the doses for all 118 chest x-ray exposures from the recorded data based on the imaging technique. The range of ESD in chest ap and chest and abdomen ap (n=103) varied from 24.8 µGy to 191.9 µGy. In chest lateral projections (n=15), the range was from 9.9 µGy to 108.7 µGy. In Group 2, the ESD for ap projections was higher than in Group 1, although the mean size of the newborns showed no significant difference (p=0.02). In lateral view, there was no significant difference in ESD between the groups (Figure 18).

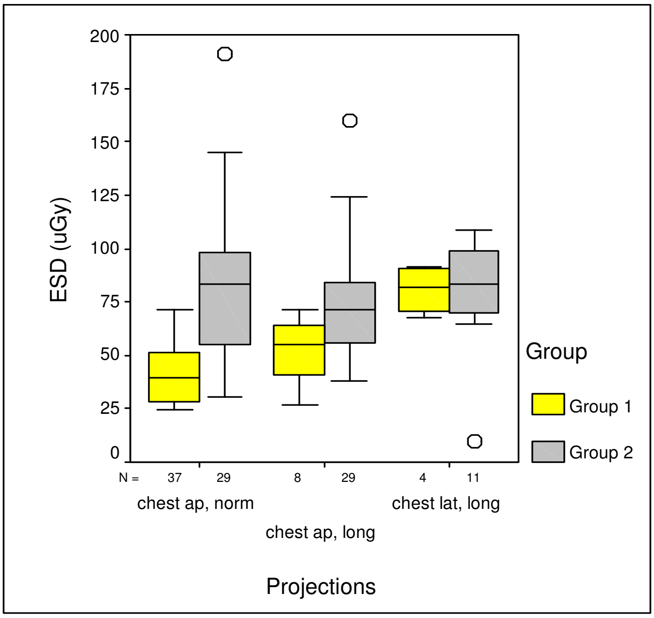

Figure 18. ESD of the chest exposure in the PICU in different projections in data groups (n=118). (Group 1 = data recorded in 1998 and Group 2= data recorded in 1999–2000).

The average ESD for newborns about 1000 g in weight was 41.9 µGy (n=37), to 2000 g in weight (n=30) 54.6 µGy and to 3000 g in weight (n=20) 74.7 µGy in chest ap and chest and abdominal ap.

As seen in Figure 19, the Dose-Area Product was higher in the latter data study both in chest ap and chest and abdomen ap but not in chest and lateral.

The effective dose for each newborn was calculated from the DAP by the PCXMC program. The range of effective dose was wider in Group 2 (Figure 20) than in Group 1. In Group 2, the newborns were on average 1.59 cm thicker, 830.7 g heavier and 4.6 cm longer than in Group 1. In this data, the biggest difference in the size of the newborns was 25.5 cm in height and 4400 g in weight.

The effective dose was higher for all projections in the second group. It was also higher in abdomen and chest ap than in chest ap due the higher exposure field.

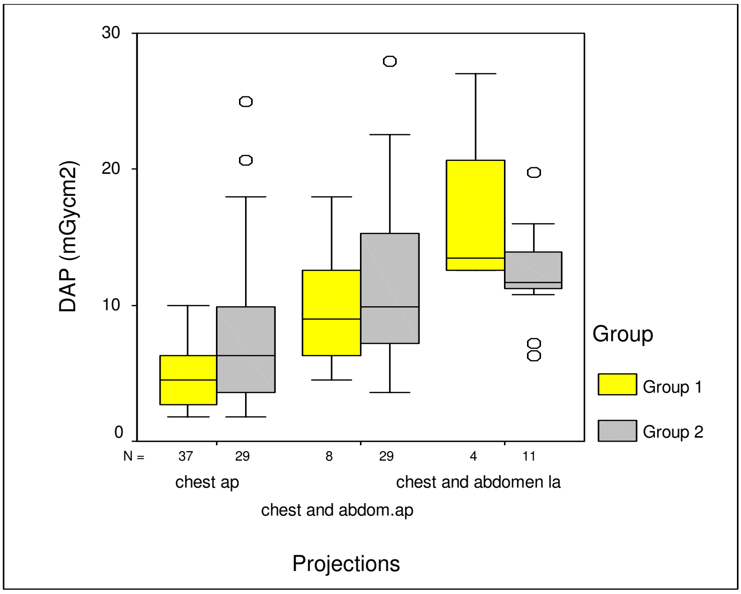

Figure 19. The Dose Area Product (DAP) mGycm² in the PICU in different projections (N=118). (Group 1 = data recorded in 1998 and Group 2= data recorded in 1999–2000).

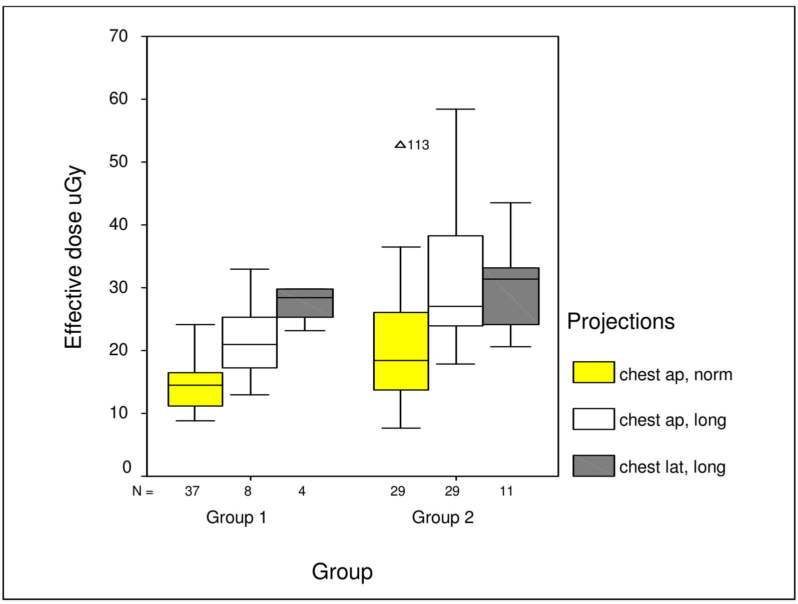

Figure 20. The effective dose of the newborns in the PICU in different chest projections (n=118). (Group 1 = data recorded in 1998 and Group 2= data recorded in 1999–2000).

The mean size (weight, height and thickness) of the newborns showed no significant differences (p=0.02) between the groups but the newborns were smaller in Group 1 (Table XX). The groups in chest lateral were too small for statistical purposes.

As seen in Figure 21, the Entrance Surface Dose, Dose-Area Product and effective dose correlate strongly. There was more correlation between ESD and DAP (r=.780) than between ESD and effective dose (r=.727). The correlation between Dose-Area Product and effective dose was highest (r=.845).

Table XX. The differences in the newborns (in height, weight and thickness) at the moment of exposure in Groups 1 and 2[*)].

	n	**Mean**	**Standard deviation (%)**	**Min**	**Max**
Height (cm)					
Group 1	37	40.0	4.69	31.5	48.50
Group 2	29	44.6	6.9	34.5	57
Weight (g)					
Group 1	37	1629	676.2	660	3050
Group 2	29	2459.8	1389.7	840	5060
Thickness (cm)					
Group 1	37	6.7	1.5	4.5	10
Group 2	29	8.3	1.7	5.5	12.5

*) Group 1= data collected in 1998 and Group 2 = data collected in 1999–2000.

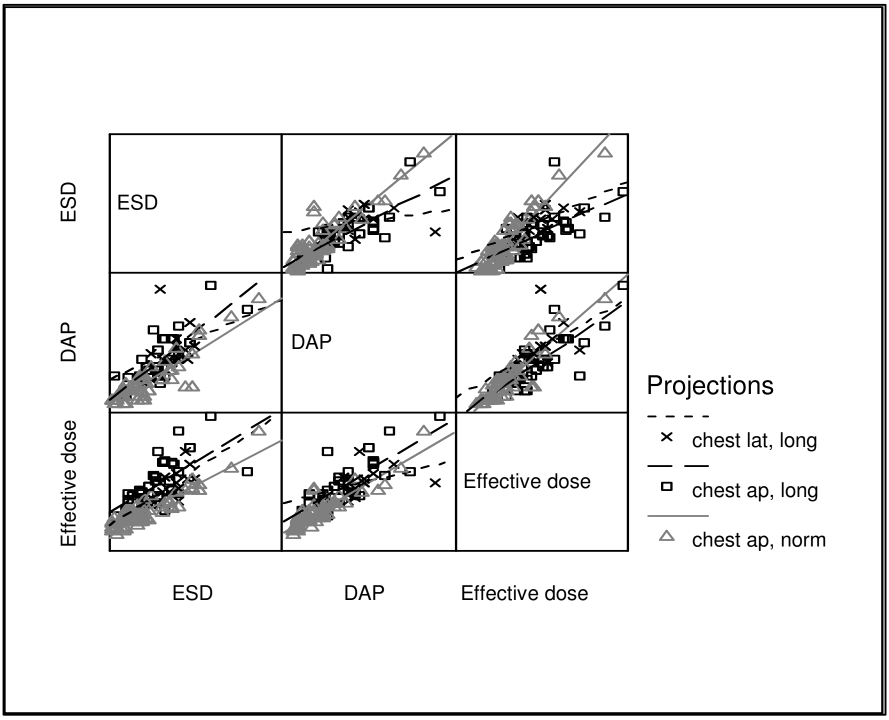

Figure 21. The correlation between the Entrance Surface Dose (ESD, µGy), the Dose-Area Product (DAP, mGycm^2) and the effective dose (µSv) in the chest examinations of the newborns (n=118).

In small newborns (under 2500 g) the effective dose did not correlate with the height of the newborn (r=.260) but the height of the exposure field and effective dose showed strong correlation (r=.751). The thickness and ESD correlate lightly (r=.562), but the range seems to be wide between two newborns of same thickness and in the same projection (Figure 22). In the chest and abdomen, the effective dose was higher due to the higher exposure area. In chest and abdomen, there was more active red bone marrow (pelvis, lumber spine) in the exposure area and the gonads were in the primary field or near to it.

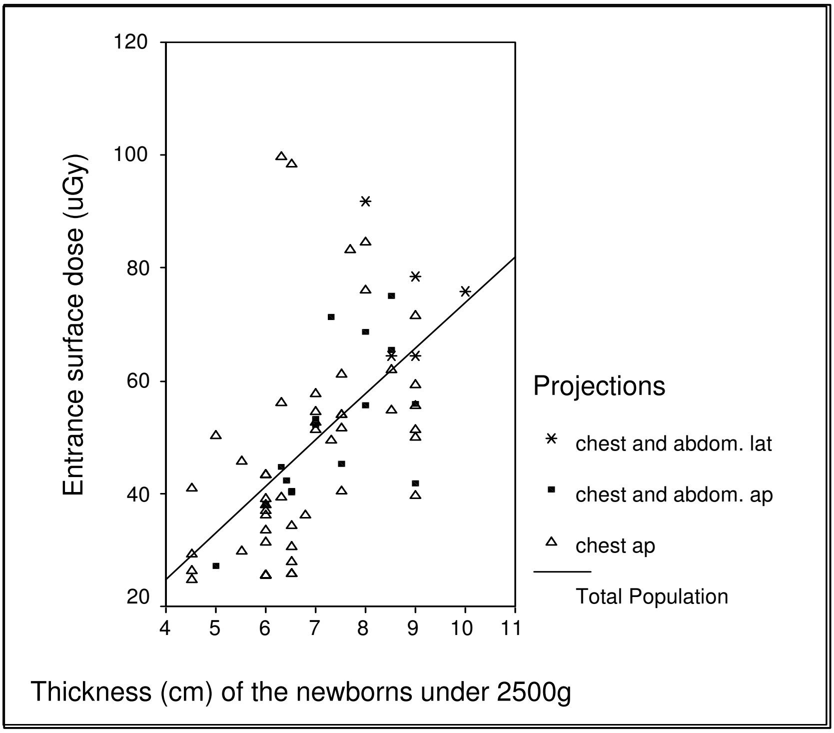

Figure 22. The correlation of the Entrance Surface Dose (μGy) and thickness (cm) of the newborns less than 2500 g in weight.

The absorbed dose to different organs is presented in Table XXI. The dose range was quite large depending on the projects and the size of the newborn. The organs located in the primary beam when having chest-x-rays (lungs and thyroid) had the same level of doses both in chest ap and chest and abdominal ap as well as the brains, which are never in the primary field. The dose to ovaries, uterus and large intestine was higher when having chest and abdomen ap. The dose to active bone marrow was somewhat higher in chest and abdomen ap than in chest ap.

Table XXI. Organ doses in different projections in the recorded data (n=118).

Organ	Average dose and dose range (mGy)			
	Chest ap (n =66)	Chest and abdominal ap (n= 37)	Chest and abdominal lateral (n=15)	All projections Mean
Ovaries	0–1	0.6–57	1–41	9
Testes	0–1	0–24	0.2–16	1
Uterus	0.1–9	1–66	1–33	9
Act. Bone*)	3–13	4–16	7–14	7
Lungs	17–95	19–79	31–58	39
Thyroid	15–150	9–89	19–86	48
Large int.**)	3–29	1–79	2–62	16
Brain	0.2–1.5	0.02–1	0.3–1	1

*) active bone marrow
**) large intestine

The average effective dose to newborns about 1000 g in weight was 16.4 µSv (n=37), to 2000 g in weight (n=30) 17.8 µSv and to 3000 g in weight (n=20) 28.3 µSv in chest ap and chest and abdominal ap.

5.2.3 The Total Number of X-ray Examinations Given to the Newborns During the Study

There were 118 recorded exposures to 43 newborns in the PICU. The total number of exposures was counted afterwards from the patient records. The total effective dose for each child was later estimated on the basis of the recorded imaging technique and other available data collected by STUK (Servomaa et al. 2000a, Servomaa et al. 2000b). If the newborn was transported to another hospital, the hospital in question was asked for the number, type and technical parameters of the x-ray examinations.

The total number of exposures (without possible unrecordered retakes) was 394 (345 chest, 30 abdomen, 11 hip joint, 4 bone age and 4 skull) exposures. There were also four barium meal examinations, including images and fluoroscopy; one newborn was given a nuclear medicine examination.

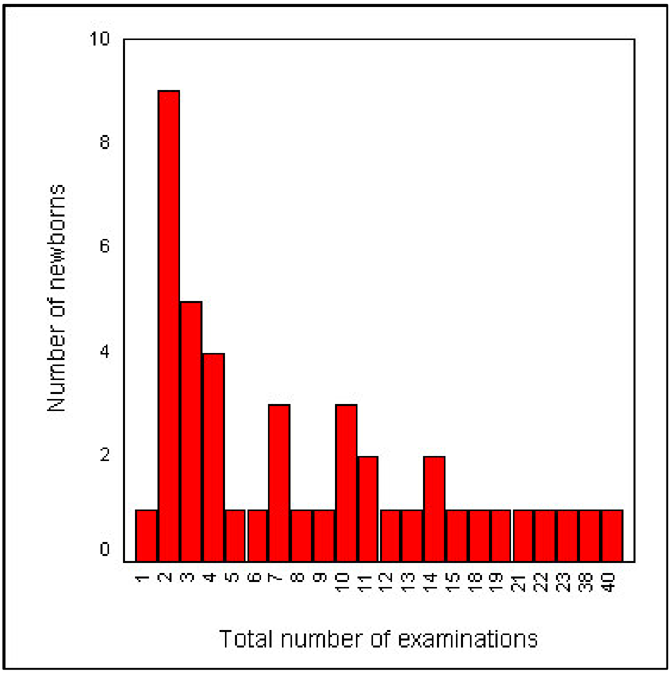

Figure 23. The total number of x-ray examinations per child during the study (n=394).

The number of x-ray examinations ranged from 1 to 40 (mean 9.3) per child (Figure 23). Five chest examinations were produced later than during the first treatment period, after birth in hospital. Hip joints and skull examinations were made during the first year of life. Mostly there were two to three examinations per newborn during the study.

5.2.4 Total Effective Dose and Radiation Risk Due to the Radiation Examinations During the Study

The estimated collective effective dose to these 43 newborns during the study was 0,016 manSv (mean 0.4 mSv, range 0.03 mSv–3.7 mSv).

The radiation risk due to these examinations varied from 0.0015% to 0.3% per mSv per newborn. The effective doses were grouped and the risk due to the dose in different dose range is seen in Table XXII.

Table XXII. The estimated risk due to the examination of these newborns (based on BEIR V and STUK 10%/Sv).

Effective Dose (mGy)	Number of newborns per group		Mean effective dose (mSv)	Risk estimation due to the radiation dose (10%/Sv)
	Female	**Male**		
< 0.1	7	13	0.058	1:100,000
0.11–0.2	5	2	0.14	1.4: 100,000
0.21–0.3	1	6	0.25	2.5:100,000
0.31–1	4	0	0.52	5.2: 100,000
1–2	1	3	1.56	15.6 :100,000
>2		1	3.68	36.8:100,000
Total	**18**	**25**		

6 Discussion

6.1 The radiation Dose to the Foetus Due to Mother's X-ray Examination

The sample collected by the questionnaires to the radiation safety officers responsible for the safe use of radiation is representative (in spite of the low percent of answers) because it includes small health centres and three of the five university hospitals. The sample is a good cross-section of Finnish practice because the distribution of the respondents represents all institutions nearly in the same relation as in the licence registry. It was quite stunning to see how varied the practice was and how uncertain the respondents were about the role of the referring physician when sending a woman of reproductive age to a radiation examination of the pelvis and the lower abdomen.

6.1.1 Pelvic and Abdominal X-ray Examinations of a Pregnant Woman

According to this study, the number of *known* pelvic x-ray examinations of a pregnant woman is quite low in Finland. Perhaps it is a consequence of the fact that 34% of the institutions did not document the x-ray examinations of a pregnant woman and 52% were sure they were not made in their departments. Those who recorded the examinations mostly documented pelvimetries. There were still 4114 x-ray pelvimetries produced (Hakanen 2002); in 1996 there were 5083 (Rannikko et al. 1997). Mostly they are made in regional or central hospitals, but are also carried out in health centres. In one regional hospital, 33% of pelvimetry x-ray examinations were made *after delivery* (for the next pregnancy) and so the foetus was not exposed. In this study, the number of pelvimetry examinations per institution varied from 4 to 234 per year. X-ray pelvimetry is a very highly skilled examination and if the number of examinations is low, the radiographer does not establish a routine to produce it. This may include the possibility of several retakes.

An x-ray pelvimetry examination is produced in the last period of pregnancy, in weeks 36–40 (Standertskjöld-Nordenstam et al. 1988), which is why the danger from the exposure gives a higher risk of childhood cancer. The International Commission on Radiological Protection 84 (2000) has proposed reducing the number of x-ray pelvimetry examinations because statistical analysis has indicated a poor correlation between the course of labour and pelvic measurements and it is the major single source of ionising radiation to the foetus. During past years, FMRI (Foetal Magnetic Resonance Imaging) has become more popular and it is recommended instead of x-ray pelvimetry (Hata et al. 1990, Revel et al. 1993, Garel et al. 1998, Resten et al. 2001).

Special consideration was given to pelvic and abdominal x-ray examinations if the patient was pregnant. A pregnant patient was sent from health centres and regional hospitals to the central hospital where experts made the decision about an x-ray examination.

It seems that in Finland, x-ray examinations, other than pelvimetry, of a pregnant woman are mostly examinations of extremities and sinus. In other countries (e.g. Ardabi 2001, Pettersson et al. 2003), there are more pelvic x-ray examinations of a pregnant women. Statistical analysis of the registers of the pelvic and abdominal x-ray examinations to women of fertile age and the register of the birth of children (cf. Pettersson et al. 2003) may lead to different results than in this study. There are about 2600 lumbar spine x-ray examinations per year in the Oulu Health Centre and 25% of them are on women aged from 12 to 50 years (Liedes 2004), and there are about 7000 x-ray examinations of the pelvic region in the Oulu University Hospital (Kylmäniemi 2004). Assuming that 25% of these x-ray examinations in the Oulu University Hospital are made on women aged 12–50 years and making a comparison with Pettersson's study, this could mean that in one year there might be as many as 30 foetal exposures in Oulu due to the mother's pelvic x-ray examinations.

The practice of having x-ray pelvimetry examinations should be seriously discussed. The advantage of x-ray pelvimetry is debatable and according to international recommendations, it should be by ultrasound or MRI examinations (World Health Organisation 1999).

6.1.2 Avoiding the Exposure of the Foetus

This study indicates that the present practise for the x-ray examination of the pelvic region (pelvis and the lower abdomen) of women of reproductive age in Finland fluctuates greatly. Neither hospitals nor health centres have guides for "good practice". The concept of a "woman of reproductive or fertile age" is very ambiguous. According to the International Commission on Radiological Protection 84 (2000) "before x-ray examination, it should be determined whether a patient is, or may be pregnant, whether the foetus will be in direct radiation beam, and whether the procedure is relatively high dose".

The possibility of pregnancy was secured for women "of fertile age", which meant strongly different age in different organisations; the lower range varied from 12 to 20 years and the upper range from 30 to 55 years. There were institutions where the possibility of pregnancy in the pelvic or abdominal x-ray-examinations of woman of reproductive age was never, or only occasionally, checked. In most institutions, there were posters on the wall of the waiting or changing room. In some cases, they relied on the patient's own responsibility.

The practice for checking the possibility of pregnancy before a pelvic x-ray examination is very heterogeneous in spite of very clear and simple guidelines. The State STM 423 (2000) states: "A referring physician has to get with appropriate questions the knowledge of the possible pregnancy of a woman of childbearing age, if the foetus may be in the exposed area. If in referral there is no comment on pregnancy, the radiographer or radiologist has to inquire about the possibility of pregnancy before the x-ray examination is produced." According this study, there was no agreement of the practice between the diagnostic radiologist departments and referring physicians concerning pelvic and abdominal x-ray examinations of women of reproductive age. This is alarming when taking into consideration the complex situation regarding the practice of excluding the possibility of the pregnancy of a woman of reproductive age who is having a pelvic or abdominal x-ray examination and whether it is being documented. If later is apparent that the patient was pregnant when having an x-ray examination, it is very difficult to determine the question of responsibility if nothing is documented. The lack of documentation causes unnecessary questions for the patient and due to these, problems with patient's privacy. In Finland, there are families who do not practice contraception because of religious conviction.

There should be posters or notices on the walls of x-ray departments and dressing rooms to inform female patients to state before an x-ray examination if they are probably pregnant. According to State STM 423, paragraph 37: "There have to be notices in the places adjoining the medical use of radiation that ask patients to announce their pregnancy and breast-feeding to personnel in order to protect the foetus and breast-feeding child".

There is no consensus of practice how to require or document the possibility of pregnancy and when it should be done. In some institutions, the ten-day rule is in use in all examinations and in some institutions, they rely on the patient's awareness.

6.1.3 The Practice in Estimating the Foetal Dose

The practice of estimating the foetal dose seemed to be a difficult problem; nearly half of the respondents (49.1%) did not answer this question. In university and central hospitals the estimator was in most cases the radiologist and/or physicist. According the National Radiation Protection Board (2001), the International Commission on Radiological Protection 84 (2000) and State STM 423 (2000), the patient’s dose should always be estimated afterwards, if needed. This means that the technical parameters of the examination must be documented carefully. If there is awareness of pregnancy before the x-ray examination and if the foetus is in the primary beam (or there is a lot of scattered radiation), the referring physician and radiologist have to discuss the necessity of the radiation procedure. If the examination is medically indicated and cannot be delayed until after pregnancy, the dose to the foetus should be estimated before the examination, calculated afterwards, and optimized carefully (International Commission on Radiological Protection 84, 2000, International Commission on Radiological Protection committee 3, 2001, European Commission 2001).

There are data for foetal doses in different examinations e.g. in publications by the International Commission on Radiological Protection 84 (2000), the National Radiological Protection Board (1998) and in many articles (Claussen et al. 1985, Osei & Faulkner 1999a, Parry et al. 1999, Toppenberg et al. 1999, Damilakis et al. 2000, Karam 2000, Mann et al. 2000, Osei & Faulkner 2000, Fenig et al. 2001, Timins 2001). They are very useful for a rough estimation especially in low-dose examinations (cf. Table III). The foetal dose estimation can be made on the grounds of the technical parameters of the abdominal and pelvic region x-ray examination, by calculating the ESD, by measuring the surface dose (TLD), or Dose-Area Product (DAP). The effective dose of the foetus can be calculated by the PCXMC (Tapiovaara et al. 1997) or FetDose (Osei et al. 2003) programs (cf. Table XVI). These are practical ways for estimating the dose because it is very difficult to get a reliable dose estimation due to the special features of a pregnant mother and the situation of the foetus (cf. et al. 1999a, Perisinakis et al. 1999).

The foetal dose estimation should be performed before the planned x-ray examination of a pregnant woman and the results should be conveyed to the woman’s physician (Karam 2000) and the dose calculated afterwards if it is so-called high dose level x-ray examination and the foetus is in the primary beam (International Commission on Radiological Protection 84, 2000, International Commission on Radiological Protection committee 3, 2001). In State STM 423 (2000), there is a demand that “The estimated foetal dose and the information important for the radiation exposure due to the x-ray examination have to be documented in the patient’s record”. For examinations other than pelvimetry, the documentation was rarely performed in Finnish health care institutions.

The dose estimation was done occasionally. There were no guidelines on how to act in situations where the embryo or foetus will be irradiated or was accidentally irradiated.

6.1.4 The Decision-Making Process for the X-ray Examinations of Pregnant Women

According to State STM 423, the referring physician judges whether an x-ray examination is justified based on the information available (previous x-ray examinations, dose, risk due to radiation and benefit to the patient). If the radiologist disagrees about the medical indications for the x-ray examination, he has to discuss the matter with the referring physician. If the radiologist still disagrees about the justification, the examination is not performed. Always when the referring physician and radiologist agree of the necessity of the exposure of the foetus, the decision has to be documented (European Commission 2001). The patient has right to make up her mind on whether the x-ray examination should be made; the opinion of the expectant mother has to be taken into consideration.

In many health centres, the radiologist visits the health centre once a week or never. This means that the referring physician and/or radiographer made the decision for the x-ray examination of a pregnant woman. In the hospitals, either the radiologist or physicist made the decision or they did it together. It is notable that the patients participated in the decision-making actively in 28% of the institutions. The comments from the respondents expressed the complicated situation in the practice: in small health centres the referring physician, the radiographer and perhaps patient had a discussion and decided if the benefit of an x-ray examination of a pregnant woman is higher than the risk to the foetus.

A pregnant woman has right to know the risks to the foetus due to an x-ray examination. The mother was told the risks mostly by the referring physician or the physician and the radiographer. Sometimes, the danger was explained by the radiographer, registered nurse or midwife and sometimes the patient was not told at all. Karam (2000) points the importance of working and reporting within one's own area of competence and this area needs a lot of discussion about who has the best knowledge and whose duty it is to give information to the patients.

There was no good practice concerning the decision-making process if a pregnant woman was irradiated. According this study, the staff in x-ray departments have no guidelines. The referring physician should have the responsibility of excluding the possibility of pregnancy, but the staff in the x-ray department did not know if this is done. The counselling for an expectant mother concerning the radiation risks to the foetus was unclear. This study did not give any answer to the question who counsels the expectant mother.

6.1.5 Guidelines for X-ray Examinations of the Pelvic Region and Abdomen of Women of Reproductive Age

Alternative investigation modalities (not involving ionising radiation) should have been considered before a decision is made to use ionising radiation as diagnostics in female patients of reproductive age. When an x-ray examination of female of reproductive age is planned and the primary beam irradiates the pelvic or lower abdominal region, she should be asked whether she is or might be pregnant. If the patient cannot exclude the possibility of pregnancy, the possible overdue to of her menstrual period should be asked. This should be recorded in an appropriate place. The pregnant patient has right to know the magnitude and type of potential radiation effects that might result from in uterus exposure. Usually the benefit from the x-ray examination is greater than the risk to the foetus due to radiation. For low-dose procedures the only information that may be needed is a verbal assurance that the risk is judged to be extremely low (e.g. chest and extremities). When the foetal dose is assumed to be above 1 mGy, more detailed explanation and counselling is needed to help the patient to make up her decision if the examination is produced or not. The information should include the potential radiation risks and the harm resulting from not having the medical procedure. (E.g. International Commission on Radiological Protection 84, 2000).

6.2 The Examinations and Dose to the Newborns

6.2.1 The X-ray Examinations of Newborns in the PICU

In 1998, there were 1,013 and in 1999, there were 969 x-ray examinations made in the PICU at Oulu University Hospital. (Kylmäniemi 2001). The recorded data included 118 chest examinations made to 43 newborns. There was some difference in the size of the newborns. In the latter group, the newborns had a weight of 710g and a height of 3.8 cm more than in the data for 1998. The chest and abdomen ap was always taken when doing the first chest x-ray of a newborn and later it was taken when the paediatrician especially required it.

In the latter data the chest and abdomen was produced more often than in the first period. The reason for this was not seen in the patient record. The most important medical diagnosis for premature infants was RDS, as in the study by Sutton et al. (1998).

Both the effective dose and Entrance Surface Dose were higher in the latter period. Probably, this was due to the thickness of the newborns and the question of image quality. This is considered to be of primary importance in children's x-ray examinations because a loss of resolution is often the only positional information required (Cook et al. 1998) and to get better image quality, the radiation dose needs to be higher (68.4 kV =>70.2 kV; 1.39 mAs => 1.7 mAs). (c.f. Kyriou et al. 1996).

The mean thickness of the newborns was 7.3 cm in the first data and 8.6 cm in the second data (a difference of 1.3 cm). Every 1 cm increase in a patient's thickness requires a 25% increase in mAs value when working without a grid less than 100 kV and a patient thickness under 15 cm (Al-Balool & Newman 1998). In addition, it became obvious in this study that the staff used the thickness of the baby as the base for estimating the mAs and kV values for exposure. This justifies the higher mAs and tube potential. When using digital image receptors, image quality is better when using more radiation, which is beneficial because the need for retakes due to under or over exposure is not probable but there is a danger that doses will get higher when seeking better image quality.

There are few studies concerning the correlation between a patient's weight and thickness and the ESD and DAP (Mooney & Thomas 1998). According to this material, they correlate with each other. (Martin et al. 1994) Wraith et al. (1995) showed a clear relationship to a patient's weight both with Entrance Surface Dose and Dose-Area Product, which was also found in this study. This relationship is important to take into consideration because there was a very wide range in the size of newborns (in weight from 0.660 kg to 5.040 kg, mean 2.285 kg and in height from 31.5 cm to 57 cm, mean *43.5* cm).

In this study, the mean value of exposures was 7.9 per child, which is somewhat higher than e.g. in surveys by Wraith et al. (1995) mean 3.8, Armpilia et al. (2002) mean 3.2, Chapple et al. (1994) mean 5.3 and McParland et al. (1996) mean 4.7 but lower than in Sutton et al. (1998) mean 9.1 or Siironen (2003) mean 14. Wilson-Costello et al. (1996) had a mean of 31 examinations and Ono et al. (2003) 25.9 with premature infants less than 750 g in weight). Ono et al. (2003) found in their study that the number of x-ray examinations is inversely proportional to the birth weight in the PICU.

The variation in field size with in the same size group of newborns and in all data was noticeable as in all other studies (Lowe et al. 1999, Cook et al. 2001, Armpilia et al. 2002, Gogos et al. 2003). That shows how difficult it is with small newborns to identify the real exposure area and limit the exposure area to the optimal size. According to Jones et al. (2001), good standards of radiographic practice are more important than the choice of technique. It seems that with digital archive, the previous images are not in use before exposure and that the size of the exposed area is difficult to judge.

6.2.2 The Dose Due to the Chest X-rays in the PICU

The European Commission (1996) issued reference values and guides for the good imaging technique for chest examinations of newborns. The ESD reference value is 80 µGy (European Commission 1996). In addition, the National Radiation Protection Board (Hart et al. 2000) has given a reference value for ESD that is lower (50 µGy) than the Em's. In this data (n=118), the mean ESD in chest ap examinations was 62.1 µGy (range 24.8–191 µGy). On average, the ESD was lower than EU reference values but higher than the NRPB's. The reasons for exceeding the dose reference values maybe in imaging technique: the thinner filtration (3 mmAl instead of EU proposal added filtration up to 1 mmAl +0.1 or 0.2 mmCu) (European Commission 1996) (cf. with e.g. Seifert et al. 1998, Fenner et al. 2002, Duggan et al. 2003). Parviainen et al. (2003) found in their study made at HUCH that the average ESD of newborns less than one month of age was a mean of 43 µGy and a DAP (mean) of 3.4 mGycm^2 but in the study by Lowe et al. (1999), the ESD ranged up to 160 µGy. Sutton et al. (1998) estimated the ESD for 498 radiographs of newborns less than 1.5 kg (mean 1.11 kg), where the ESD varied from 15.3 µGy to 73.9 µGy; the mean was 33.1 µGy per radiograph. In chest examinations, the mean ESD was 31.9 µGy and in chest and abdomen, 43.7 µGy. Ono et al. (2003) studied doses to the neonates for a birth weight less than 2.5 kg. In their study, the range of the ESD was from 170 µGy to 720 µGy for neonates under 1 kg and the range was from 70 µGy to 149 µGy for neonates from 1 kg to 2.5 kg.

According to several studies (Fletcher et al. 1986, Chapple et al. 1994, Wraith et al. 1995, Kyriou et al. 1996, McParland et al. 1996, Sutton et al. 1998, Armpilia et al. 2002, Ono et al. 2003, Samei et al. 2003, Toma 2003), the tube potential varies from 46 kV to 70 kV and mAs from 0.4 mAs to 2 mAs. The mean ESD per radiograph varied from 16 and 70 µGy. The results of this study agree with those published earlier. Duggan et al. (2003) recommend a tube potential of 66 kVp with a 0.05 hafnium filter for chest x-ray examinations of infants under 2 kg.

In Armpilia's (2002) study, the weight of the newborns was from 1.1 kg to 1.7 kg (mean 1.5 kg) on average. In this study, there were 36 exposures to newborns under 2 kg, all premature infants. Table XXIII gives a summary of this size group, comparing it with Armpilia (2002). The most noticeable differences are in tube potential voltage (~10 kV) and effective dose.

In the three CEC paediatric Trials in 1989–1995, the average Entrance Surface Dose measurements from paediatric radiography in a chest ap was 0.045 mGy for a newborn weighing 1 kg, which is at the same level as in this study (European Commission 1996). The NRPB's (Hart et al. 2000) reference level for newborns (without weight limits) is somewhat higher, 0.05 mGy. Table XXIV shows the results of this study and gives examples of reduced doses with attention to good technique in Queen Mary's Hospital for Children (Cook et al. 1998). The ESD is much higher in all weight groups in this study but the effective dose is lower except for the group of the smallest newborns. This may be due to the fewer chest and abdomen examinations of the bigger infants in weight.

Table XXIII. Summary of the study of premature infants' (0.66 kg–1.7 kg) estimated doses and, including radiographic data, patient data, compared with Armpilia (2002).

	Chest ap		Chest and abdomen	
	This study range (mean)	**Armpilia average**	**This study range (mean)**	**Armpilia average**
Weight (kg)	0.66–1.7 (1.2)	1.7	0.8–1.74 (1.1)	1.1
Thickness (cm)	4.5–7.5 (6.2)	-	6–7.5 (6.7)	-
kV	66–70 (67.6)	53.1	66–68 (67.8)	52.2
mAs	1–1.6 (1.3)	2	1.25–1.6 (1.4)	2
DAP (mGycm^2)	1.8–6.3 (3.5)	4.3	3.6–8.1 (5.8)	5.5
ESD (µGy)	24.8–99.8 (40.8)[*)]	36[**)]	38.0–71.3 (47.5)[*)]	35[**)]
Effective dose (µSv)/radiograph	7.56–27.5 (14.1)	7.8	18.4–43.6 (25.9)	9.2

*) with BSF
**) Without BSF

Table XXIV. Entrance Surface Doses and effective doses of the chest ap of the newborns of different weights in this study and in Cook's et al. (1998) study of a department with good attention technique.

Weight (kg)	ESD (mGy)		Effective dose (mSv)	
(range/mean in this study)	This study mean (range)	Cook (1998) mean	This study mean (range)	Cook (1998) mean
1 (n=37) (0.66–1.49/1.04)	0.04 (0.03–0.1)	0.01	0.16 (0.01–0.4)	0.02
2 (n=30) (1.56–2.48/2.14)	0.06 (0.03–0.08)	0.02	0.02 (0.01–0.03)	0.04
3 (n=20) (2.51–3.39/2.91)	0.08 (0.06–0.08)	0.03	0.03 (0.01–0.05)	0.07

When both chest and abdomen radiographs are needed, a significant dose reduction can be achieved by taking one chest and abdomen exposure instead of two (chest and abdomen separately) because it eliminates overlapping (Duggan et al. 2003).

6.2.3 The Total Number and Dose Per Child Due to all X-ray Examinations During the Study

There were 398 x-ray examinations and one nuclear medicine examination made to these 43 newborns during the study. The most common examination was chest or chest and abdomen. Only a few skull, bone age and hip joint examinations were produced. This is the same range as in other studies (Wilson-Costello et al. 1996, Siironen 2003). The majority of the radiographs were performed during the newborn period (the first month after birth). In the study by Wilson-Costello et al. (1996), the range was same for chest radiographs but in this study, there was no noticeable increase in the number of abdominal exposures at a later age. In the study by Ono et al. (2003), the most usual examinations in the neonatal intensive care unit were babygrams (chest and abdomen) and chest but in the large data, there were also a lot of CT examinations of head and abdomen and fluoroscopy examinations.

6.2.4 The Risk to a Newborn Due to an X-ray Examination

In ICRP 60 (1991), the risk of fatal childhood cancer due to pre-natal exposure has been estimated to vary from $2.8 \cdot 10^{-2}$ Sv^{-1} to $13 \cdot 10^{-2}$ Sv^{-1}. The authors stress that the risk is greater during the first trimester than in later pregnancy. If it could be accepted that the risk is same in the later periods, the risk due to radiographs taken shortly after birth (and especially of premature infants) should be similar as the risk of foetus. In this case, the risk of childhood cancer from one single radiograph would be $(3–13) \cdot 10^{-5}$.

For the 43 children in this study, the total effective dose to the whole population due to x-ray examinations was 0,016 manSv and the mean effective dose was 0.37 mSv. One child received an effective dose on 3.68 mSv due to the nuclear medicine examination. The radiation risk of fatal childhood cancer due to a mean dose of 0.37 mSv is $3.7 \cdot 10^{-5}$.

6.3 Reliability of the Study and Results

The reliability of the study was improved by using a tested questionnaire based on the form model from STUK. The number of returned questionnaires was 173 (60%). Some of the respondents were radiation safety officers responsible for the safe use of radiation in two or three places, as they stated in the returned questionnaire (cf. Servomaa 2003). The results of the survey showed that in the early phase there was no common practice on how to act when performing an x-ray examination of the pelvic region on a woman of reproductive age. This led to the decision not to send reminder letters or new enquires because it was presumed the results would not improve. The distribution of the returned questionnaires well represents the distribution of the hospitals and health centres having x-ray equipment (cf. Hakanen 2002). Perhaps some institutions did not answer because of the lack of good practice. The nature of this study was a representative and reliable and showed a bad lack in the safe use of medical radiation. This resulted in changing the nature of this study and a proposal for a guide in good practice was designed.

The reliability of the study into the doses given to newborns was improved by recording the data during the day shift and using three radiographers. They always recorded the data thoroughly and consistently. The patient records were analysed in the archive and they were kept anonymous. The doses counted based on the recorded data was reliable when taking into consideration the reliability of the DAP meter but the doses to other exposures are estimations and only show the level of the received doses. The researcher made the dose calculations of the ESD and effective dose by herself and the results of the calculations were checked twice. The risk estimation was based on the practices of STUK, BEIR V and ICRP. Risk estimation involves uncertainty but in this study, the risk estimation due to the radiation dose is at the same level as it is in international studies. The results of the doses to the newborns or the total number of x-ray examinations cannot be generalised. They provide good reference levels for the future – for using new digital equipment in paediatric departments and for optimising the radiation dose. A larger number of newborns would have given results that are more reliable but in this study, they are examples of the doses and of the number of x-ray examinations to one risk group that should be studied more carefully. Probably, the most ill newborns were not included in the data.

6.4 Ethical Issues

The ethical issues of this study are dual. The questionnaire to the radiation safety officers responsible for the safe use of radiation was sent and received by the authority on the basis of their registry. The respondents were all on duty and one of their responsibilities was to give information to the Radiation Safety Officer of Finland. The institutions were grouped in health centres, regional hospitals, central hospitals and university hospitals. Individual institutions could not be identified.

Permission to collect the data on the newborns was applied for from the ethical board of the Faculty of Medicine at Oulu University Hospital. The system for collecting and recording the data was designed and tested together with the staff in the paediatric x-ray department. Dose follow-up is an important area of quality assurance and it should be carried out annually, which is why the permission of the parents was not sought. If the parents were nearby, they were informed about the data recording of the doses. The problem in paediatrics is the huge variation in the size of the patients. Some of these newborns may also have been critically ill. This data collection did not endanger the chance of these newborns recovering from their illnesses (cf. Laki lääketieteellisestä tutkimuksesta 1999). The doses to the newborns had not recently been studied and in particular, there was no retrospective study of the doses to newborns in Finland.

Permission for the study of the patient records was applied for from Oulu University Hospital. The patients' records only were handled in the archive. The patients' records were searched according to the time they were cared for in the PICU and on the basis of the examinations made to each child. The exposure dates, examination and patient weight and height formed the critical information about the newborn. The identity of the newborn was not recorded on the worksheets; all that was used was a consecutive number for each newborn. An individual newborn cannot be identified from the data. The data sheets will all be destroyed. (c.f. Brockopp & Hastings-Tolsma 2003.)

6.5 General Discussion

This study showed that there is no common practice on how to document the x-ray examinations of a pregnant woman or to exclude the possibility of pregnancy in x-ray examinations of a woman of reproductive age. In some institutions, they believe that the patient is aware of the risks and informs the staff by herself; in other institutions, the ten-day rule is in practice. Neither was there any practice on how to act if a pregnant woman is exposed (accidentally or on purpose). In Finland, there are families who do not use birth control due to religious reasons and it is possible for those mothers to become pregnant soon after an earlier delivery. In most institutions, there was no practice or guides for foetal dose estimation. Degree 423/2000 by the Ministry of Social Affairs and Health is quite new and probably this is the reason why as yet there are no guidelines for good practice in this area.

According this study, nobody had taken responsibility for advising a pregnant woman about the risk to the foetus due to x-rays. The law on a patient's rights (1992) as well as the STM degree 423/2000 points out a patient's right to participate in the decision-making process concerning her health and illness, treatment and investigation. The referring physician should discuss with patients about the doses due to ionising radiation and alternative modalities. The referring physician should also exclude the possibility of pregnancy. It was obvious, according this study, that there is not yet any good practice. The staff of a radiological department rarely knows if the referring physician has had the discussion and excluded the possibility of pregnancy. The radiographer or radiologist who performs the x-ray examination also has the duty to check the possibility of pregnancy.

To improve this practice, this study presents a proposal for a guide to good practice in the pelvic x-ray examinations of a woman of reproductive age (Appendix F). It includes guidelines on how to exclude and document the pregnancy of a woman of reproductive age coming for a pelvic or lower abdominal x-ray examination and guidelines for foetal dose estimation and documentation (Tables III, XVI and EI, Appendix E). It will be published later in Finnish.

The results of this study show that the risk from one neonatal radiograph is low. However, the benefit versus risk of each radiograph is important and must be checked carefully. Radiation effects are cumulative and some children may have dozens of x-rays and maybe a nuclear medicine examination. There are also some risk groups e.g. children with vesicoureteral reflux who due to diagnostic and follow-up examinations may receive doses of up to 11 mSv during to the age of sixteen years (Kettunen et al. 2003) and in the study by Fotakis et al. (2003) 0.31 (+/-0.86) mSv for male patients and 0.28 (+/-0.76) mSv for female patients per examination to the age of five years. Another, small but important risk group is children undergoing heart investigations. The dose conversion factors for a 9 kg patient (1 year old child) are 1.8 mSv/Gycm^2 in frontal view and 1.4 mSv/Gycm^2 in lateral view (Axelsson et al. 1999). Some of these children may receive x-ray or nuclear medicine examinations for other reasons and in these cases, the dose can be much higher (cf. Siironen 2003).

The wide range of doses in the PICU needs the continual assessment of radiation dose in the neonatal nursery. The almost universal under collimation on all sites is conspicuous. Collimation does not affect the ESD but it is very important for effective dose reduction especially with very small newborns and premature infants because the organs are in or very close the primary radiation beam. Two centimetres is quite a large difference in a newborn 32 cm in height and in an exposure area 6 cm high. However, this shows the demands set on caring for the infants.

By making sure that only essential radiographs are taken, the staff can optimize the radiation dose to a newborn. In addition, collimation of the radiation beam so that only the relevant organs are in the exposure area and the use of radiation shields are important ways of optimising the radiation dose to newborns. In this study, these were not recorded separately because they are always in use.

The newborns often lie in an incubator and need help with breathing and other vital functions. It is important to maintain a stable body temperature. For this reason, it is important to work quickly and gently when taking x-rays of a newborn. Extra noise, an open window on the incubator or a careless touch may course harm and pain to the baby. All this requires the radiographer producing the x-ray examination to have high professional skill.

Digital imaging gives new possibilities to postprocess an exposed x-ray and decrease the need for retakes or extra exposures: e.g., edge enhancement to copies of neonatal chest radiographs helps to identify small pneumothoraces and vascular catheters (Goo et al. 2001) and gives increased contrast and the possibility to transfer images quickly via teleradiology to a specialised paediatric radiologist (Tarver et al. 1990, Pohjonen et al. 2002). Routine daily chest radiographs may give new information to the paediatrician in 50% of the cases of very low birth weight infants (Greenough et al. 2001). According to Oeppen et al. (2002), "the chest x-ray is not recommended in the initial evaluation of the asymptomatic neonate with heart murmur". This data was collected at the end of the 1990s. The equipment is still the same. Dose optimisation is made all the time. According to the study by Siironen (2003), the doses are at the same level today.

The latest results of the Swedish study (Hall et al. 2004) into the effects of radiation dose to the brains of infants are alarming. Intellectual development can be disturbed if the infant's brain is exposed to ionising radiation at doses equivalent to those caused by head computed tomography. The use of radiation must be considered carefully and the use of MRI instead of CT is important. The need for retrospective studies into the influence of the radiation dose from all radiation examinations even at the individual level is obvious. The importance of radiation dose optimisation sets new challenges on the training of radiographers. According to Chan et al. (1999), it is possible to get a reduction of 40% in radiation dose in cranial CT, and according to Ratcliffe et al. (2003) 50% in a paediatric pelvic CT, without the loss of image quality. If the CT parameters used for paediatric patients are not adjusted on the basis of examination type, age and/or size of the child, the doses are unnecessarily high. In the study by Pages et al. (2003), one unit had same protocol in head CT for adults and children and this resulted in an effective dose of 17.1 mSv to a five year old and 10.5 mSv to an adult. Dose estimation and dose optimisation in CT is constantly becoming more reliable (e.g. Chapple et al. 2002, Akahane et al. 2003). Helical and multi slice CT offers great possibilities for imaging children but its sensible use requires good communication and consultation between the paediatrician and radiologist. One important strategy for minimising the radiation dose to children is to limit the number of CT examinations by evaluating the appropriateness criteria for the CT examinations of children (Frush et al. 2003).

Adequately trained radiographers should perform the examinations on newborns and children. Together with the radiologist, they can maximize dose optimisation without losing good image quality.

This study has raised many aspects for new tasks to be studied. A statistical analysis of the registers for the pelvic and abdominal x-ray examinations of women of fertile age and the register for children born could produce new information (cf. Pettersson et al. 2003). There are no studies concerning the information given by a referring physician to a woman of reproductive age. Neither is it known how often and the way in which the referring physician uses the knowledge of the radiation doses and alternative imaging modalities and if Radiation Protection 118 (the guide for sending a patient for an imaging examination) is widely spread and in every day use.

The increased use of CT and MDCT (multi slice CT or multi detector CT) produces high dose examinations (e.g. UNSCEAR 2000, Pages et al. 2003). New routine examinations are produced for such things as appendicitis and for trauma patients (Berland & Smith 1998, Frush 2002). There are a lot of dual phase (pre and post contrast) CT examinations. CT scans are retaken to ensure the diagnosis or for the follow-up to treatment. Optimisation of the imaging technique, especially in the CT examination of children, should be made by decreasing the number of slices, using a low-detail setting when possible (tube current) and setting clear indications that make it easy to produce the scan. There are not yet reference levels for children's doses in CT.

New imaging receptors (imaging plates and flat panels) offer new possibilities to decrease a radiation dose but this demands a lot of work. The image quality should be good enough, not the best. This means that all x-ray examinations are made individually based on the patient and the information about what the referring physician is looking for. The optimisation of the imaging technique with digital receptors needs a slightly different practice than optimising the dose with film-screen combination. New knowledge and studies are required to achieve the best quality with a minimum dose.

Accurate measurement of the radiation doses to children can be difficult because the doses are rather low, which is why the dose measurements and dose estimation must be done very carefully. The choice of dose descriptor and its extrapolation to radiation risk need careful consideration. The risk factors for different stages of infancy and childhood may be considerably different from the risk factors of the whole population. Retrospective studies of the doses or follow-up studies of the radiation doses for some risk groups could be useful in estimating the risk due to radiation. A paediatric radiation logbook could be useful.

This study may help a radiological department to get good practice in the pelvic x-ray examinations of a woman of fertile age. To get more information about the reactions of an expectant mother in these situations, a new study based on interviews should be performed. In addition, a follow-up study of children irradiated in uterus would give interesting information. The risk groups should be found and special attention should be paid to the dose optimisation in their x-ray examinations.

One interesting and important area for study is the dose estimation to the foetus. It should be done, but who has duty to do it? Will it in future be one competent area of radiographers, who have studied medical physics and radiation protection in their further studies in university? Dose estimation is also very problematic in health centres where there is no physicist, not even a radiologist.

This study has raised many new thesis ideas for radiographer students, as seen above. This study clearly shows how important it is to train radiographers. Dose optimisation and guidelines for good practice in the radiation field need a lot of work. Radiographer students can also inform clinical departments about their new ideas. It is obvious that more multi professional co-operation is needed in training health care professionals in all fields of activity.

7 Conclusions

The requirements set in Degree 423/2000 are not totally fulfilled in Finnish practice.

I The number of x-ray examinations of a pregnant woman was not found because the institutions did not document such cases or they stated that such examinations have not obviously been produced. Only x-ray pelvimetry examinations were documented.

II There was no common practice in Finland for excluding the possibility of the pregnancy of females of reproductive age when having an x-ray examination of the pelvic or lower abdomen region. The “reproductive age” is unclear. Neither is there agreement about the practice of by who, when and how the dose to the foetus due irradiation is estimated nor who counsels the expectant mother about the radiation risk to the foetus. About 50% of the institutions had no methods or practice for foetal radiation dose estimation and their opinions were that they did not need any methods because they did not x-ray a pregnant woman.

III The effective dose to the newborns (gestational age from 26 weeks to 42 weeks, mean 34 weeks) in the PICU due to radiological examination was on average 7.81 μSv per radiograph. The mean ESD was 0.159 mGy (range from 0.008 mGy to 0.16 mGy) per x-ray examination and the mean DAP was 8.54 $mGycm^2$ (range from 1.8 $mGycm^2$ to 27.9 $mGycm^2$). Chest and abdomen projection was always performed during the first exposure but also later. The height of the exposure area varied widely in the same projection with the newborns of same height. About 36% of the newborns needed help with breathing and quite often, a chest x-ray was performed after extubation.

IV The mean effective dose to these newborns due to all radiological examinations during the study was 0.37 mSv per child. There was some uncertainty in estimating the risk of cancer. Recent studies have shown other detriments to children due to irradiation. The children may receive many x-ray examinations, which is why dose optimisation must be performed every time. The total radiation dose should be followed up, especially with children and young patients.

V The radiation risk is rather low. The risk due to a mean effective dose 0.37 mSv is $3.7 \cdot 10^{-5}$.

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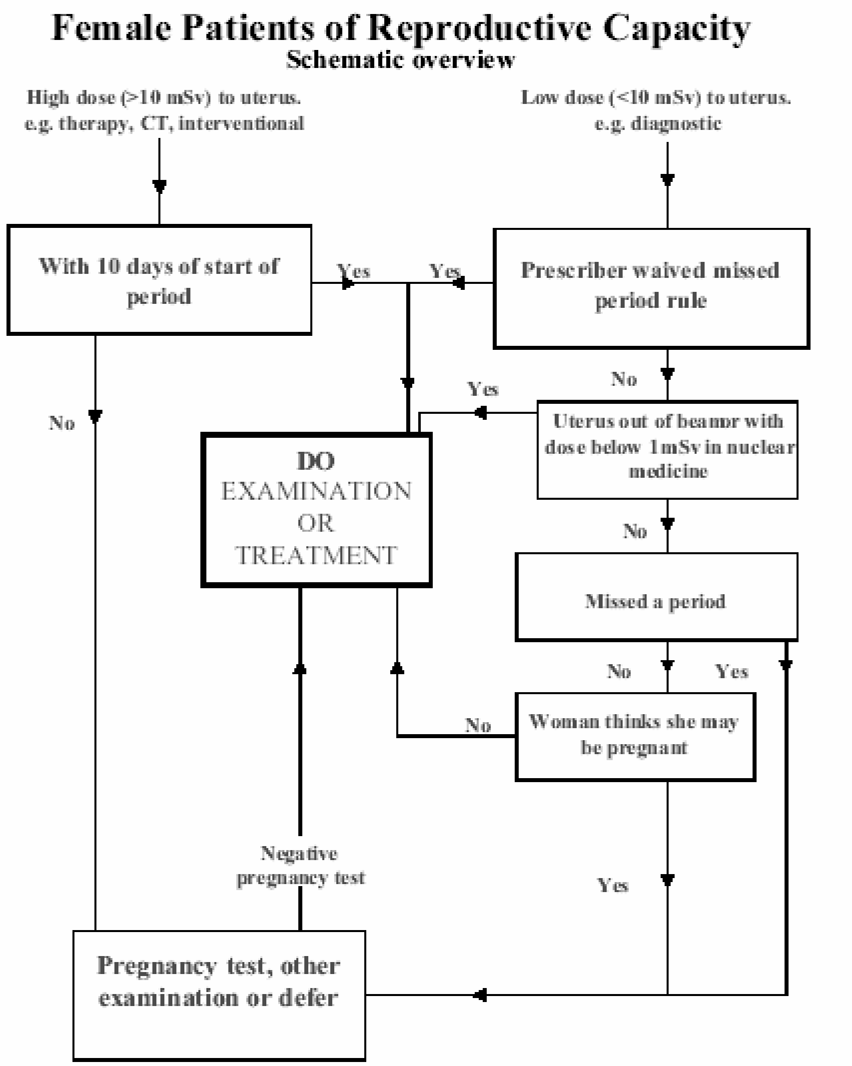
Appendix A: Schematic Overview of Excluding the Probability of Pregnancy

(Adopted from the European Commission 1998, Radiation Protection 100).



Appendix B: An Information Poster to Woman in Reproductive Age

An information poster on the wall of the radiological department to capture the attention of a woman of reproductive age to advise her to announce the possibility of ther pregnancy before an X-ray examination.

Appendix C: Normalized Conceptus Doses in Abdomen AP and PA

kVp	Conceptus depth (cm)	Total filtration (mm Al) 2.5	3.0	3.5	4.0	4.5
60	4	0.046	0.049	0.052	0,055	0.057
	6	0.069	0.074	0.078	0.082	0.087
	8	0.099	0.106	0.112	0,118	0.122
	10	0.138	0.147	0.157	0.165	0.175
	12	0.193	0.206	0.216	0.227	0.237
	14	0.248	0.264	0.280	0.294	0.304
70	4	0.067	0.072	0.076	0.081	0.083
	6	0.098	0.105	0.111	0.120	0.124
	8	0.140	0.148	0.157	0.163	0.170
	10	0.194	0.205	0.216	0.227	0.236
	12	0.261	0.274	0.288	0.303	0.316
	14	0.332	0.350	0.367	0.378	0.395
80	4	0.093	0.098	0.103	0.108	0.112
	6	0.130	0.137	0.143	0.153	0.159
	8	0.181	0.191	0.201	0.209	0.216
	10	0.248	0.260	0.274	0.285	0.295
	12	0.323	0.339	0.355	0.367	0.380
	14	0.404	0.424	0.441	0.455	0.472
90	4	0.110	0.117	0.122	0.125	0.129
	6	0.160	0.166	0.172	0.179	0.184
	8	0.217	0.227	0.235	0.243	0.251
	10	0.291	0.306	0.318	0.328	0.339
	12	0.376	0.395	0.412	0.426	0.441
	14	0.464	0.486	0.505	0.520	0.535
100	4	0.128	0.134	0.139	0.144	0.149
	6	0.181	0.189	0.195	0.202	0.208
	8	0.245	0.256	0.266	0.276	0.284
	10	0.328	0.341	0.354	0.366	0.376
	12	0.426	0.443	0.457	0.472	0.484
	14	0.518	0.538	0.554	0.568	0.585

kVp	depth (cm)	Total filtration (mm Al) 2.5	3.0	3.5	4.0	4.5
60	4	0.73	0.763	0.792	0.811	0.835
	6	0.492	0.519	0.542	0.567	0.583
	8	0.322	0.338	0.357	0.376	0.387
	10	0.214	0.228	0.241	0.251	0.261
	12	0.143	0.153	0.16	0.163	0.174
	14	0.087	0.097	0.098	0.105	0.108
70	4	0.828	0.856	0.886	0.911	0.935
	6	0.588	0.612	0.643	0.662	0.679
	8	0.399	0.423	0.443	0.458	0.476
	10	0.278	0.299	0.31	0.322	0.332
	12	0.188	0.193	0.204	0.211	0.220
	14	0.124	0.134	0.138	0.142	0.151
80	4	0.915	0.947	0.973	0.991	1.014
	6	0.665	0.693	0.718	0.734	0.756
	8	0.466	0.487	0.513	0.532	0.549
	10	0.337	0.355	0.368	0.383	0.395
	12	0.225	0.238	0.249	0.262	0.271
	14	0.153	0.166	0.17	0.174	0.183
90	4	0.976	1.000	1.025	1.048	1.068
	6	0.731	0.755	0.779	0.795	0.819
	8	0.531	0.553	0.571	0.585	0.604
	10	0.384	0.398	0.415	0.426	0.439
	12	0.266	0.277	0.292	0.302	0.312
	14	0.184	0.195	0.201	0.208	0.212
100	4	1.019	1.044	1.07	1.087	1.106
	6	0.776	0.800	0.824	0.836	0.854
	8	0.576	0.595	0.618	0.633	0.644
	10	0.423	0.437	0.451	0.468	0.479
	12	0.297	0.306	0.321	0.332	0.340
	14	0.204	0.218	0.224	0.227	0.233

Normalized conceptus dose data in mGy /mGy for PA abdomen (A) and AP abdomen (B) examination performed on pregnant patient during the first postconception weeks according to Damilakis et al (2002)

Appendix D: Questionnaire to the Radiation Safety Officers

Selvitys raskaana olevien naisten röntgentutkimuksista

Säteilyn käytöstä vastaava johtaja

Sosiaali- ja terveysministeriön säteilyn lääketieteellistä käyttöä koskevassa asetuksessa (423 / 2000) kiinnitetään erityishuomiota raskaana olevien naisten röntgentutkimusten säteilysuojeluun ja altistuksen optimointiin. Tämän tutkimuksen tarkoituksena on arvioida suomalaista käytäntöä ja verrata sitä annettuihin suosituksiin. Toivomme Teidän vastaavan liitteenä oleviin kysymyksiin sairaalanne osalta. Liitteenä olevalla tietojenkeruulomakkeella (LOMAKE 1) selvitetään, kuinka raskauden mahdollisuus yleensäkin varmistetaan / suljetaan pois fertiili-ikäisiltä naisilta, kuinka sikiön säteilyaltistus määritetään, mitkä ovat tavallisimmat raskaana olevalle naiselle tehtävät tutkimukset sekä millainen tutkimusprotokolla ja -tekniikka niissä on.

Liitteessä on mukana myös Säteilyturvakeskuksen laatima lomake "Raskauden aikainen röntgentutkimus" (LOMAKE 2) annoslaskennassa tarvittavien tietojen dokumentointia varten. Mikäli sairaalassanne on jo aiemmin dokumentoitu raskaana olevalle tehdystä röntgentutkimuksesta tutkimustietoja, toivomme Teidän täyttävän lomakkeen tiedot mahdollisimman tarkoin po. tilannetta vastaavaksi. Tietoja käytetään arvioitaessa tutkimuksesta sikiölle aiheutunutta säteilyaltistusta.

Pyydämme palauttamaan molemmat lomakkeet kirjeen mukana olevassa kirjekuoressa 17.12.2000 mennessä. Tiedot käsitellään ehdottoman luottamuksellisesti ja yksittäiset vastaukset jäävät vain tutkijoiden tietoon.

Vastaamme mielihyvin kysymyksiinne.

____

Anja Kettunen, THM,
Yliopettaja
Oulun Seudun Ammattikorkeakoulu
Oulun Yliopisto, Lääketieteellinen
tiedekunta

____

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LOMAKE 1(6)

Rastita mielipidettäsi / osastonne käytäntöä vastaava numero / vaihtoehto tai kirjoita vastauksesi sille varattuun tilaan.

terveyskeskus ___ aluesairaala ___ keskussairaala___yliopistosairaala__

1. Kuinka monta lantion ja vatsan alueelle kohdistuvaa röntgentutkimusta sairaalassanne tehtiin raskaana oleville äideille 1999?

________ tutkimusta, joista _______ natiivi-, ________ pelvimetria-, ______ läpivalaisu- ,

________ tietokonetomografiatutkimuksia, joku muu, mikä ____________________.

Ko. tutkimuksia ei tehty ___________, ko. tietoa ei ole dokumentoitu ___________.

2. Kuinka sairaalassanne raskauden mahdollisuus varmistetaan / suljetaan pois ennen vatsaan tai lantioon kohdistuvaa röntgentutkimusta fertiili-ikäiseltä naiselta?

____

____

3. Minkä ikäisiltä naisilta sairaalanne röntgenosastolla kysytään raskauden mahdollisuutta ?

___________________________________ -vuotiailta

4. Miten tieto raskauden mahdollisuudesta / poissulkemisesta röntgenosastolla dokumentoidaan?

____

____

5. Arvioi, kuinka usein tulee lantion tai vatsan alueelle kohdistuneen röntgentutkimuksen jälkeen ilmi, että potilas olikin raskaana tutkimusta tehtäessä?

Keskimäärin _________ kertaa kuukaudessa / vuodessa (**alleviivaa ajanjakso**).

6. Raskaana olevalle tehdyn lantion tai vatsan alueen röntgentutkimuksen yhteydessä sikiön säteilyaltistuksesta tehdään ________ ei tehdä __________arviota.

Jos arvio tehdään, niin kuka arvioi sikiön säteilyaltistuksen po. tutkimuksessa?

1. Radiologi
2. Sairaalafyysikko
3. Lähettävä lääkäri
4. Röntgenhoitaja
5. Joku muu, kuka

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(2/6)

7. Milloin sikiön säteilyaltistus arvioidaan?
    1. Ennen röntgentutkimuksen suorittamista
    2. Tutkimuksen jälkeen
    3. Annosarvio tehdään potilaan kysyessä annosta
    4. Annosarviota ei tehdä
    5. Muulloin, milloin ____

8. Miten sikiön säteilyaltistuksen arviointi suoritetaan?
    1. Kirjallisuuteen perustuen
    2. Laskennallisesti
    3. Mittaamalla (esim. TLD, fantomi)
    4. Muuten, miten ____

9. Kuka päättää viimekädessä, tehdäänkö raskaana olevalle röntgentutkimus vai ei?
    1. Lähettävä lääkäri
    2. Radiologi
    3. Säteilyn käytöstä vastaava johtaja
    4. Röntgenhoitaja
    5. Fyysikko
    6. Potilas itse
    7. Joku muu, kuka____

Tarvittaessa lyhyt selvitys käytännöstä:

____

____

10. Kuka kertoo raskaana olevalle äidille röntgentutkimuksesta aiheutuvasta säteilyriskistä?
    1. Lähettävä lääkäri
    2. Radiologi
    3. Säteilyn käytöstä vastaava johtaja
    4. Röntgenhoitaja
    5. Fyysikko
    6. Kätilö / sairaanhoitaja
    7. Annetaan potilaalle kirjallista materiaalia
    8. Joku muu, kuka ____
    9. Ei kukaan

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(3/6)

11. Miten raskaana oleva äiti reagoi kuullessaan odottamansa lapsen säteilyaltistuksesta ja siitä lapselle koituvasta riskistä?

1. Pelästyy
2. Ahdistuu
3. Haluaa tietää enemmän asiasta
4. Ei reagoi mitenkään
5. Suhtautuu välinpitämättömästi
6. Halua raskauden keskeytyksen
7. Muuten, miten ___________________________________

12. Onko odotus- ja pukeutumistiloissa tiedotettu mahdollisen raskauden ilmoittamisesta henkilökunnalle ennen röntgentutkimuksen suorittamista?

Kyllä _______ Ei _______

13. Kuinka usein ja millaisissa tilanteissa raskaana olevan lantion tai vatsan alueen röntgentutkimus muutetaan ultraääni- tai magneettitutkimukseksi?

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(4/6)

Toivomme Teidän vielä antavan seuraavat tutkimustekniikkaan liittyvät tiedot sikiön säteilyaltistuksen arvioimiseksi. Tutkimustekniikkaan liittyvät tiedot voivat olla **joko todellisia** raskaana olevalle potilaalle käytettyjä, tai ellei sellaisia ole, raskaana olevalle **todennäköisesti käytettävät** ("ohjearvot") kuvausparametrit ja tutkimusprotokolla.

14.1 Raskaana olevalle äidille tehtävän **natiiviröntgentutkimuksen tai urografian** projektiot ja kuvausparametrit ovat tyypillisesti:

Tutkimus ja projektio	Tutkimuksen indikaatio	kV	mAs	kenttäkoko cm^2 filmillä (leveys x korkeus)	DAP ($mGycm^{2)}$)
lanneranka AP					
lanneranka sivu					
LV					
lantio					
lonkan AP					
lonkan lauenstein					
lonkan axiolateraali ("läpiammuttu")					
pelvimetria interspina					
pelvimetria sivu					
häntäluu					
sacrum					
S-I-nivelet					
natiivimaha					
urografia, iso AP					
urografia, munuaisten kohta					
urografia, viisto					
urografia, rakkokuva					

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(5/6)

14.2 Toivomme, että kuvailisitte alla olevaan tilaan **raskaana olevalle äidille lantion tai vatsan** alueelle tehtävässä **läpivalaisututkimuksen indikaation sekä** käytettävät projektiot, kuvausparametrit, läpivalaisuajan sekä mahdollisesti tutkimuksessa potilaalla käytettävät lyijykumisuojat ja niiden sijainnin:

Passage:____

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Colongrafia:____

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Angiografia (mikä?)

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(6/6)

Muu tutkimus / toimenpide, jossa läpivalaisua:

14.3 Toivomme, että kuvailisitte alla olevaan tilaan raskaana olevalle äidille **lantion tai vatsan** alueelle tehtävässä **tietokonetomografiatutkimuksessa** käytettävät kuvausparametrit: kV, mAs, leikkeiden paksuus ja lukumäärä, kuvausalue sekä mahdollisesti varjoainetehostuksen käytön

Kiitos!

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LOMAKE 2(3)

15. Raskauden aikainen röntgentutkimus

Mikäli sairaalassanne on jo aiemmin dokumentoitu raskaana olevalle tehdystä röntgentutkimuksesta tutkimustietoja, toivomme Teidän täyttävän lomakkeen tiedot mahdollisimman tarkoin po. tilannetta vastaavaksi.

Sairaala- ja potilastiedot:

Sairaala:

Potilastiedot: Ikä _______ Pituus _____ Paino ______
Raskausviikko ___________
Tutkimus: Natiivi ___ Läpival_____ TT _____ Muu _____

15.1 Natiivitutkimus:

Röntgenlaite: ____

Tutkimus/projektio* ____

Kuvausarvot: FFD ____ Suod. _____ kV _____ mAs _____

Kenttäkoko filmillä _____ Annos (jos mitattu) _____

Sikiö primäärikeilassa Kyllä_____ Ei _____

Kuva tutkimuskohteesta Piirrä tarvittaessa kentän sijainti lomakkeen takana olevaan kuvaan

Tutkimus/projektio*
Kuvausarvot: FFD _____ Suod. _____ kV _____ mAs _____

Kenttäkoko filmillä _____ Annos (jos mitattu) _____

Sikiö primäärikeilassa Kyllä_____ Ei _____

Kuva tutkimuskohteesta Piirrä tarvittaessa kentän sijainti lomakkeen takana olevaan kuvaan

*Tiedot jokaisesta projektiosta erikseen (jatka tarvittaessa kääntöpuolelle)

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15.2 Tietokonetomografiatutkimus: **(2/3)**

Röntgenlaite:		
Tutkimus:	Leike _____	Spir./ helical _____
Tutkimuskohde:		
1) Tutkimustekniikka*:	kV ____	mAs / pyörähdys _____
	Leikkeiden lukumäärä tai kokonais- mAs _____	Leikepaksuus _____
	Leikkeiden välinen siirto _______________	
Sikiö primäärikeilassa	Kyllä ___ Ei _____	
Kuva tutkimuskohteesta:	Piirrä tarvittaessa kentän sijainti lomakkeen takana olevaan kuvaan	
2) Tutkimustekniikka*:	kV ____	mAs / pyörähdys ____
	Leikkeiden lukumäärä tai kokonais- mAs ____	Leikepaksuus ____
	Leikkeiden välinen siirto _______________	
Sikiö primäärikeilassa	Kyllä ____ Ei ____	
Kuva tutkimuskohteesta:	Piirrä tarvittaessa kentän sijainti lomakkeen takana olevaan kuvaan	
* Jokaisesta leikesarjasta (natiivi, varjoaine) tiedot erikseen		

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15.3 Röntgenläpivalaisututkimus: **(3/3)**

Tutkimus/Projektio				
Tutkimusarvot:				
Kuvaus*:	Kuvien lukumäärä _____	FFD _____		Suod. _____
	kV _____	mAs _____		
	Kenttäkoko filmillä ____________________			
	Annos (jos mitattu) ____________________			
Sikiö primäärikeilassa	Kyllä _____	Ei ______		
Läpivalaisu:**	kV _____ mA _____	Lpv-aika _____		Annos _____
Sikiö primäärikeilassa	Kyllä _____	Ei _____		
Kuva tutkimuskohteesta:	Piirrä tarvittaessa kentän sijainti lomakkeen takana olevaan kuvaan			

*Tiedot jokaisesta projektiosta erikseen, jos mahdollista, muuten keskimääräiset tiedot
**Keskimääräiset tiedot, jos tarkkoja tietoja ei ole käytettävissä

15.4 Muu tutkimus
(Käytä soveltuvin osin edellisiä taulukoita)

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KIITOS VASTAUKSISTANNE!

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Appendix E: Estimated Foetal Doses for the CT

Table EI. Estimated foetal dose for the CT of the abdomen or pelvis with the foetus in the primary beam by 120 kVp, slice thickness 5 mm or more

Multi-slice helical CT(4 detector)		**Single helical CT**	
technique	**Dose mGy**	**technique**	**Dose mGy**
300 mAs, pitch 4.5	35	300 mAs, pitch 1	35
300 mAs, pitch 6.5	25	300 mAs, pitch 1.5	25
200 mAs, pitch 4.5	23	200 mAs, pitch 1	23
200 mAs, pitch 6.5	15	200 mAs, pitch 1.5	15
150 mAs, pitch 4.5	17.5	150 mAs, pitch 1	17.5
150 mAs, pitch 6.5	12.5	150 mAs, pitch 1.5	12.5
(El-Khoury & Madsen 2003)			

If the slice is 3 mm, the increase in dose is 10–20%; for a 1 mm slice, the increase is 30–40% and 0.5 mm slice 50–150% depending on the manufacturer.

Appendix Fa: Proposal for a Guide to Good Practice in the X-ray Examination of the Pelvis and Lower Abdomen of Reproductive Age or for a Pregnant Patient

General principles

Both the foetus and children are more radiosensitive than adults are. The main consequence following in-utero or childhood exposure at a few or a few dozen doses typical in the diagnostic use of radiation is cancer induction. The utero radiation risks can be compared with natural spontaneous risks. For example, the natural cumulative risk of fatal childhood cancers in England and Wales to the age 15 years is about $7.7 \cdot 10^{-4}$(National Radiological Protection Board 1993a) and approximately 73% of all human conceptions abort before the 6th week of gestation (Mole 1979, Boklage 1981).

X-ray *pelvimetry* examinations should be reduced and replaced with MRI. If there is no possibility of MRI, the imaging technique has to be optimised properly. X-ray pelvimetry should be performed only with a strong indication.

In addition, other x-ray examinations should be considered carefully when the patient is a woman of reproductive age. Alternative techniques not involving ionising radiation should be considered before a decision is taken to use ionising radiation. The imaging technique and the number of exposures should be optimised and lead shields should be used when possible to shield the radiosensitive organs.

Posters or bulletins with a picture of a pregnant mother and an informative text should to be placed on the walls of *every* x-ray department waiting room and dressing room to tell female patients aged from 12 to 50 years that they should inform the staff before an x-ray examination if *she feels she* may be pregnant (e.g. menstrual period is overdue) or she is trying to become pregnant or she is sure she is pregnant. The text should be both in Finnish/ Swedish and in English (Appendix II). It should be stressed in the patient information that the MOST IMPORTANT thing a patient can do is to tell to her doctor if she is pregnant or thinks she might be. The symptoms of pregnancy are such things as nausea, vomiting, breast tenderness or fatigue. The patient has the right to participate in the decision-making process concerning whether to perform the x-ray examination.

The radiographer should be very tactful when the patient is a young girl. If her parents are nearby, she should be asked the question about her possible pregnancy in a separate room in order to get a reliable answer.

Always, when producing radiological procedures involving exposure of the lower abdominal or pelvic regions of women of reproductive age, the radiographer or radiologist must ensure that the radiation dose received is as low as practicable. The exposure technique, projection (ap/pa) and number of exposes (including retakes) have to be documented in all pelvic or abdominal x-ray examinations of woman of reproductive age (as well as in all other examinations of every individual).

It can be assumed that women who have been sterilised are not pregnant. It must be stressed that the use of an oral contraceptive pill or intrauterine device does not guarantee non-pregnancy. Therefore, whether a woman of reproductive age is or may be pregnant and whether the foetus is in the direct beam and the procedure is relatively high-dose should be determined before all x-ray examinations. If the patient is unconscious or too sick to answer, the radiographer should ask the family or attending physician. If the answer is not a clearly negative “no”, and if time permits, a pregnancy test should be performed.

In emergencies, if the female’s life is in a danger, immediate action must be taken. In such cases, it is especially important that the risk to the unborn child be estimated after the examination in order to provide further considerations.

Before Irradiation

Radiation doses due to most radiological procedures present a rather small risk to the embryo or foetus. For examinations above the abdomen or below the hips, the pregnant patient should be assured that there is no scientific evidence that the radiation dose due to the examination will result in any detectable harm to the foetus. Shielding the abdomen and pelvis with lead aprons should be used.

If the foetus will be in direct beam or near it, the x-ray examination should be delayed until after the pregnancy. The prescriber as well as the practitioner (radiographer or radiologist) should be involved in optimising the dose to the foetus. If the patient documents make no mention that the possibility of pregnancy has already been checked by the practitioner in very recent past, the radiographer or radiologist should ask the every female patient of reproductive age orally or in written form about this before giving an x-ray. The answer should be documented in the patient record. The recommended manner is to give to a patient coming to an x-ray examination of the pelvic region or lower abdomen a form to fill in, sign and return to the radiographer before the x-ray examination (Appendix E). The forms should be archived at least for two years in the radiological department. If the patient is not sure that she is or might be pregnant, she should be treated as if she were pregnant.

If the patient is or may be pregnant and the embryo or foetus may be exposed, the referring physician must ensure that the benefit from the examination is greater than the risk to the embryo or foetus and that earlier examinations and other possibilities to examine the patient have been deliberated upon.

The foetal dose must be estimated if the foetus is in the direct beam (x-ray examination of pelvis or abdominal region). In low-dose (under 10 mSv) examination, the foetal dose can be estimated on the basis of literature (Tables III, IV, VII and Appendix E) during the first two months of pregnancy. The foetal dose is also cumulative and increases the risk of fatal cancer to the child up to the age of 15 years. The referring physician has to inform the expectant mother about the risk to the foetus due to radiation. The patient makes the final decision about whether to perform the x-ray examination.

In high-dose examinations (CT and barium enema), the ten-day rule should be applied or a pregnancy test performed.

During the X-ray Examination

If an x-ray examination of the pelvic or abdominal region is performed on a pregnant patient, the imaging technique and number of exposes have to be optimised carefully. The imaging technique (projection, field size, number of films for each projection, kVp, mAs, and the filtration of the unit used) has to be documented. The beam collimation must be done carefully and appropriately to the very specific area of interest. Removing the anti-scatter grid and increasing kVp can reduce the foetal dose. Pelvic shielding should be used if possible. Fluoroscopy should be limited to be as short as possible and all fluoroscopic procedures must be timed. A written record of the fluoroscopy time, kVp and mA, use of grid, geometrical description, projections and exposures must be made. If the Dose-Area Product meter is in use, the dose should be recorded. Repeat exposures must be eliminated and retakes should not be taken before consulting the radiologist. For CT examinations, the mAs and kV should be reduced to the lowest level and taking into consideration the diagnostic quality. The slice thickness should not be less than 5 mm.

After Irradiation

In x-ray examinations with a foetal dose 10 mSv or more (CT-, barium-enema, interventions with fluoroscopy and uterus in or near direct radiation beam), the radiation safety expert can make the dose calculation after the x-ray examination. The foetal dose must be recorded in the patient record.

All cases of the accidental irradiation of a foetus or embryo should be, for the sake of all concerned, documented in institutions and reported to STUK. The risk rarely justifies the termination of a pregnancy.

Appendix Fb: A Sheet for Excluding the Possibility of Pregnancy

A sheet for excluding the possibility of pregnancy in a woman of reproductive age (12–50 y) coming to an x-ray examination of the pelvis or lower abdomen

Consent for the x-ray examination of woman of reproductive age coming to an x-ray examination of the pelvic region or lower abdomen

(Patient confirming that she is not pregnant)

Patient's name ____

Date of birth ____

Are you pregnant? Yes________ No__________

What kind of contraceptives do you use?

Implanted contraceptive device (hormone implants, intrauterine coil) ______

Oral contraceptive pill and have not missed a pill in the last month _______

Have you had your womb removed or have been sterilised?_______

Are you no longer having periods (post menopausal at least 2 years)? ______

Have you had sexual intercourse since your last period? _______

Your period is late but you had a negative pregnancy test today _______

Pregnancy test result ____________

Signature of staff __________________

I am very unlikely to be pregnant due one or some of the above reasons. I understand that there are risks to an unborn child if I have a radiation test when pregnant

I consent to the examination being performed

Date ___________________ Signature of patient _______________________

Print name _______________________